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GL-TR-89-0098



# Prototype Instrumentation and Design Studies

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Scientific Report No. 1



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GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731-5000

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Flight prototype sensor systems using spherical sections and electrostatic deflection are being developed, fabricated, tested and calibrated. The detectors will measure the flux of ions and electrons over a 100° x 10° angular fan and in 32 discrete energy levels from 10 eV to 10 KeV. This report describes the sensor system design for an instrument package for shuttle flight as well as studies being performed investigating the feasibility of using strip detectors to produce a multiangular solid state detector for high energy particles and the use of time of flight techniques for mass determination and a correlator to look for wave-particle interactions.

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FIGURES

PRDA-QR1

# PROTOTYPE INSTRUMENTATION AND DESIGN STUDIES

AMPTEK, INC.
6 De Angelo Drive
Bedford, MA 01730

January 8, 1988

R&D Status Report
September 4, 1987 throught December 31, 1987

Contract #F19628-87-C-0094

## NESTED 270 DEGREE ELECTROSTATIC ANALYZER

Initial design studies and computer modeling calculations were started on an electrostatic analyzer (ESA) system using nested 270 degree quadrispheres. The outer set of spherical deflection plates will be used for ion analysis and the inner pair for electron measurements. Initial design assumptions have been that the ion sensor will require a sensitivity of 1E-03 cm squared steradian and the electron sensor will be approximately ten to one hundred times less sensitive than the ion sensor. This sort of system could be used in a low to medium earth orbit where the ion densities are ten to a hundred times less than the ambient electron flux. This sensitivity differential would yield similar ion/electron counting statistics for that environment.

The dimensions and characteristics of the deflection system that was modeled are:

| | | |
|---|---|---|
| Ion Plates: | Outer Radius | = 2.3 inches |
| | Inner Radius | = 1.7 " |
| | Aperture | = 0.067 " |
| Electron Plates: | Outer Radius | = 1.125 inches |
| | Inner Radius | = 0.875 " |
| | Aperture | = 0.039 " |

A preliminary estimate of the response of this system indicates that the ion plates could sample an incoming flux within an angular acceptance of 120 degrees by 12 degrees. If the broad angle response were divided into ten 12 degree sectors, then these individual sectors would have a sensitivity of 1E-03 cm squared steradian, the initial design goal. The plates would have an analyzer constant of 3.33 and an energy resolution of 1.7%.

The electron plates would likewise view more than 120 degrees, but the narrow fan angle would be 10.5 degrees. Assuming an identical 12 degree sector for the electrons yields a sensitivity of 3E-04, an analyzer constant of 4 and an energy resolution of 2%. The geometric factor of the electron deflection plate pair can be adjusted by varying the aperture diameter. An inlet aperture of .0039 inches reduces the response sensitivity to 2.6E-06.

These initial estimates were manually calculated and do not take into consideration detector efficiencies, angular modulation of the effective aperture, deflection plate field inhomogeneities, and other second order effects on real ESA systems. These preliminary plate and aperture dimensions are being run on a computer model that contains most of these variables and various performance and design trade offs are being considered.

The nested spherical design offers a compact measurement module, but the mounting and electrical isolation of the deflection plates and electron multipliers presents a mechanical design challenge. Several plate mounting methods have been attempted and a method that provides both the isolation and mechanical rigidity necessary for space flight has been identified.

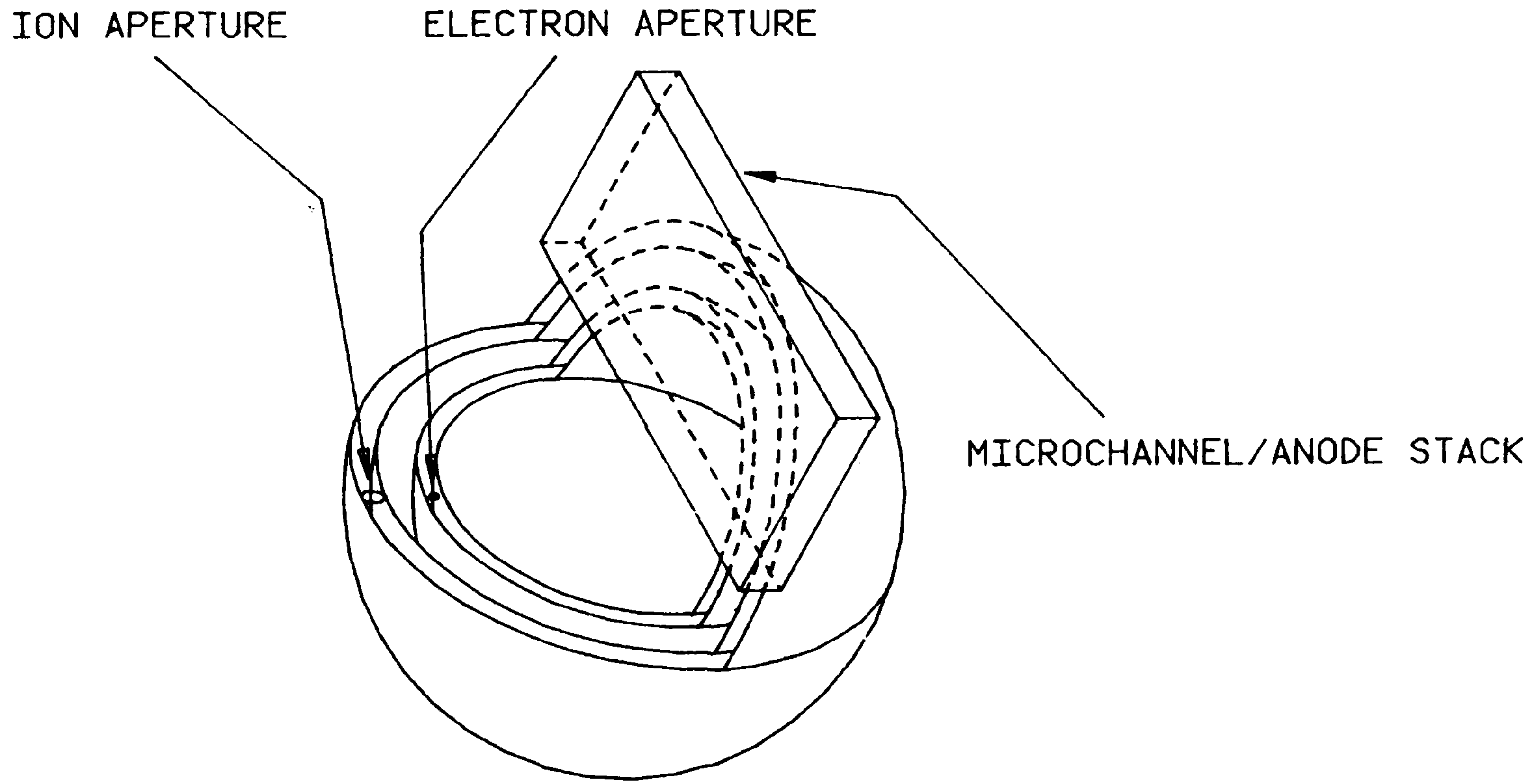
In order to extend the angular coverage of this sensor, a system using motor driven rotary platforms has been investigated. Two rotating nested pairs will achieve full 2 pi response.

This sensor design will produce large quantities of data that could require on board data processing if there is not a substantial telemetry bandwidth to transfer the raw data to a ground station. A sensor control device is being designed to increase the versatility of the ESA. The work done on this control unit is covered elsewhere in this report.

Since this ESA configuration can measure simultaneous ion/electron fluxes made over a broad magnetic pitch angle distribution, the experiment offers a unique opportunity to examine the raw data stream for statistically significant particle bunching that may occur in certain wave/particle interactions. To make this type of measurement the feasibility of including a particle correlator in the data processing has been studied. A University of Sussex expert in this field (Dr. Paul Gough) has been contacted about this possibility.

Vendors of several types of electron multipliers have been contacted to identify suitable candidates for the sensor system multiplier. Laboratory experiments to evaluate some of these microchannel electron multiplier arrays have been conducted. We are looking for a source of large area multiplier plates that have good output pulse height distribution and are rugged enough for a space experiment. Samples from two manufacturers have been obtained and are being evaluated.

The possibility of including a data recording device as part of the experiment is also being explored. Tape recorders, Winchester type hard disks, video recorders, and optical disk recorders are being researched to identify manufacturers of ruggedized systems capable of space flight.




NESTED PAIR ESA

FIGURE QR1-1

Nested Sensor Pair Mounted with Data Processing Unit and Recorders

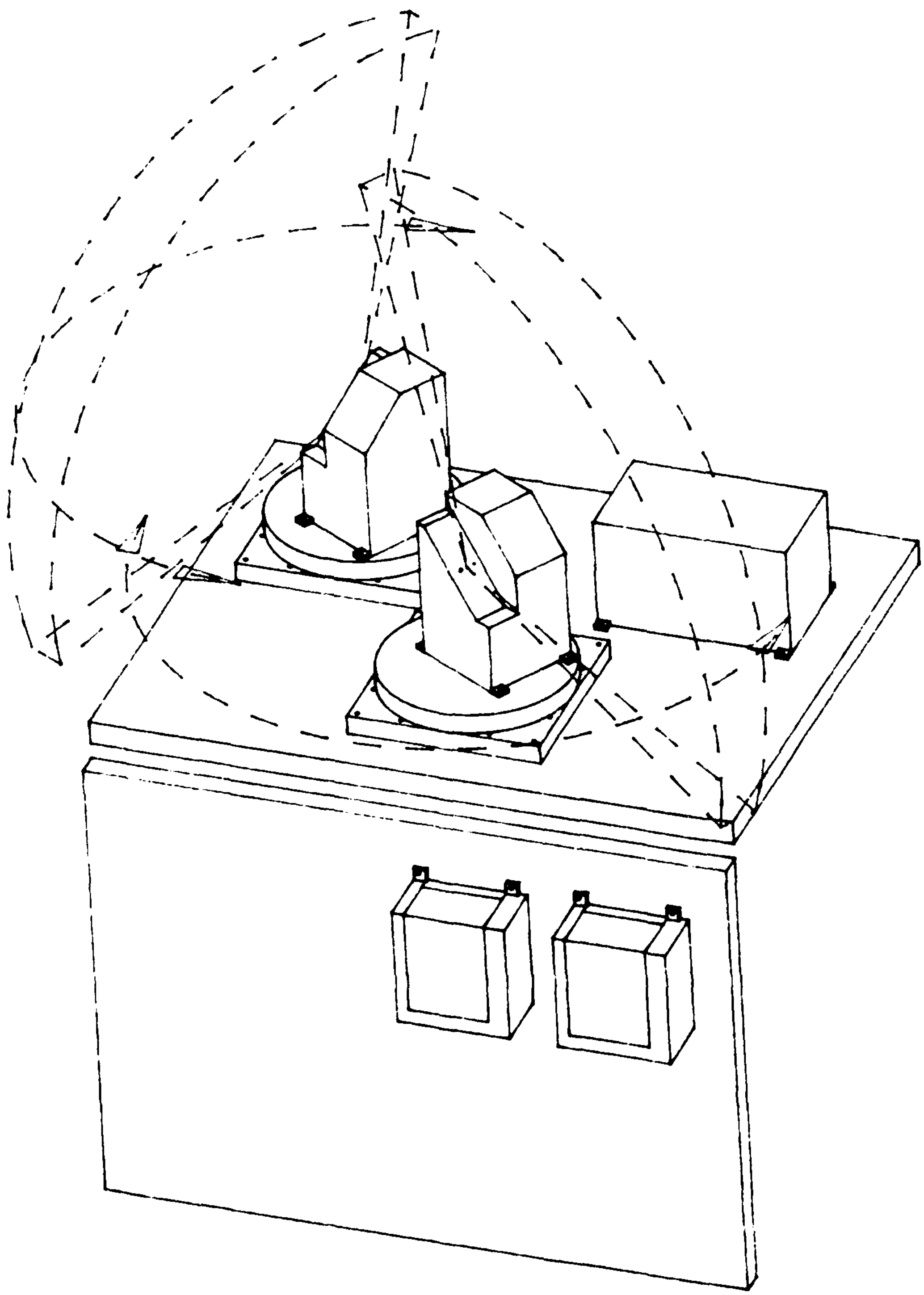
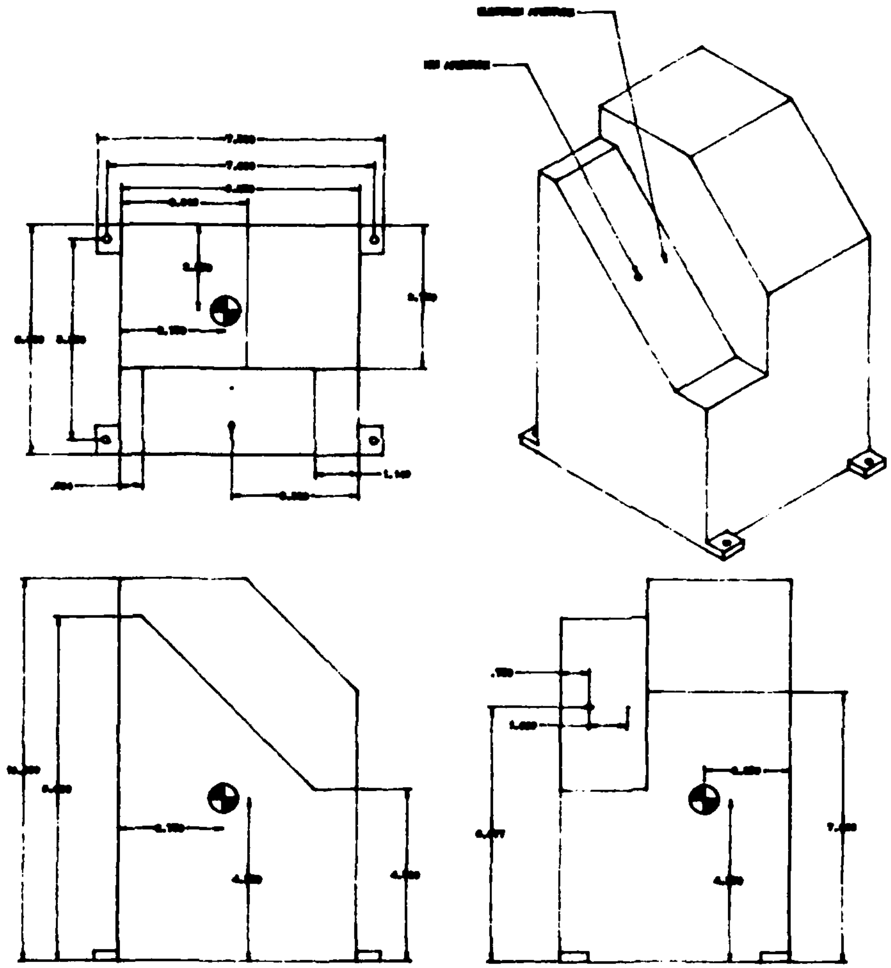


FIGURE QR1-2

Sensor Housing



POWER DISSIPATION : 5.5 WATTS

WEIGHT : 9 POUNDS

FIGURE QR1-3

Motor Drive for Sensor Orientation

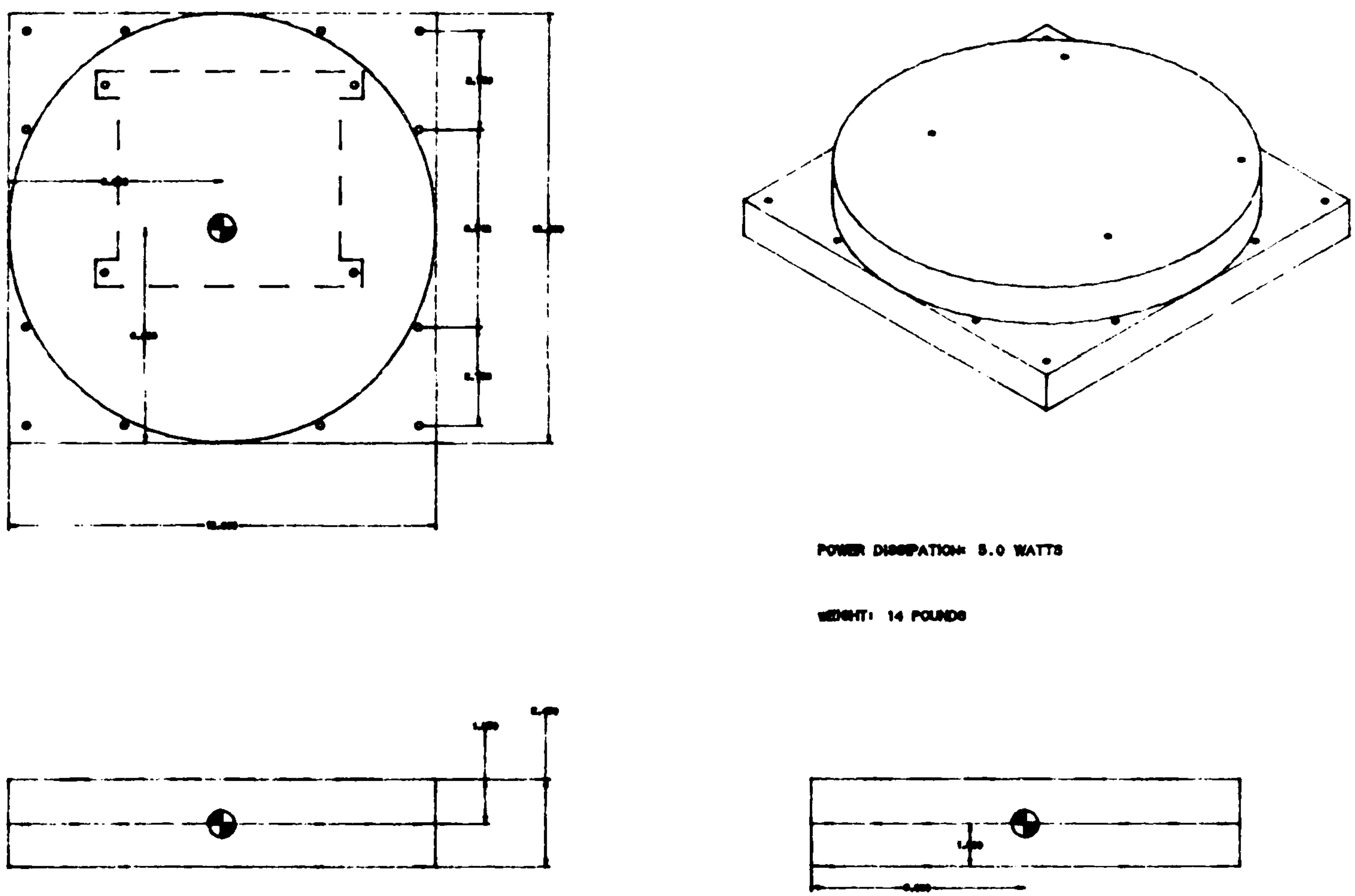



FIGURE QR1-4

Tape Recorder

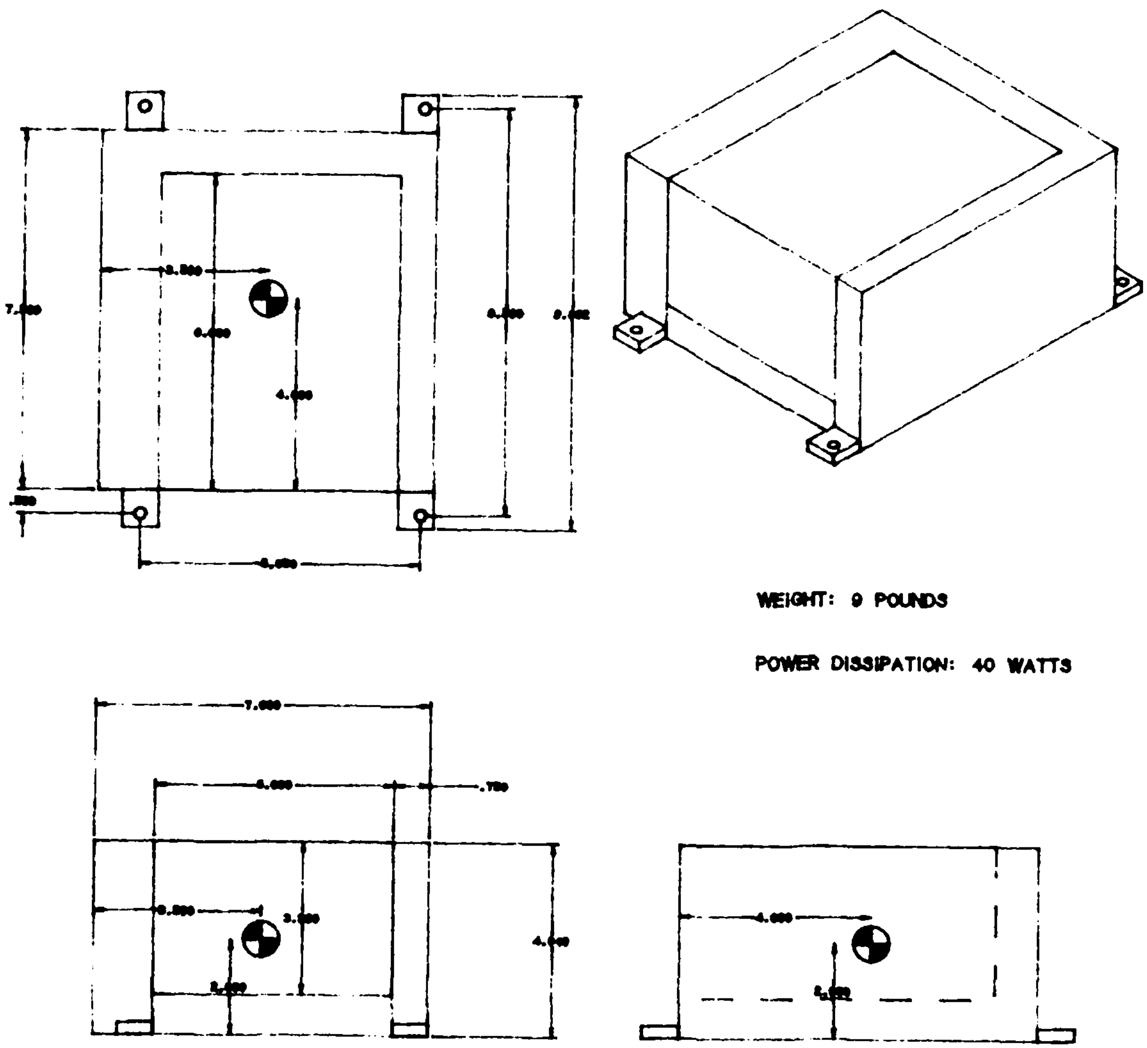



FIGURE QR1-5

## DATA PROCESSING UNIT FOR 270 DEGREE NESTED SENSORS

The Data Processing Unit (DPU) is in the conceptual design stage. Because the data requirements remain unknown, the present configuration is a dual-CPU system. This configuration should allow sufficient processing overhead for the estimated data requirements.

In this configuration, one CPU is dedicated to data acquisition from the sensors and particle correlator, and controls the high voltage. It performs all of the data analysis and transfers only the relevant data to the second CPU.

The second CPU is responsible for formatting the data received from the first CPU and transferring it to the data recorder. It is also responsible for controlling the motion system and monitoring the environment. Communications with the spacecraft are controlled through this CPU.

Each CPU has its own local program and data memory, and other necessary peripherals. The only interconnection between the two CPUs (other than power) is a 16-bit bidirectional data bus. This bus allows the transfer of timing information, mode control, and sensor data between the two CPUs.

# DATA PROCESSING UNIT FOR NESTED SENSORS

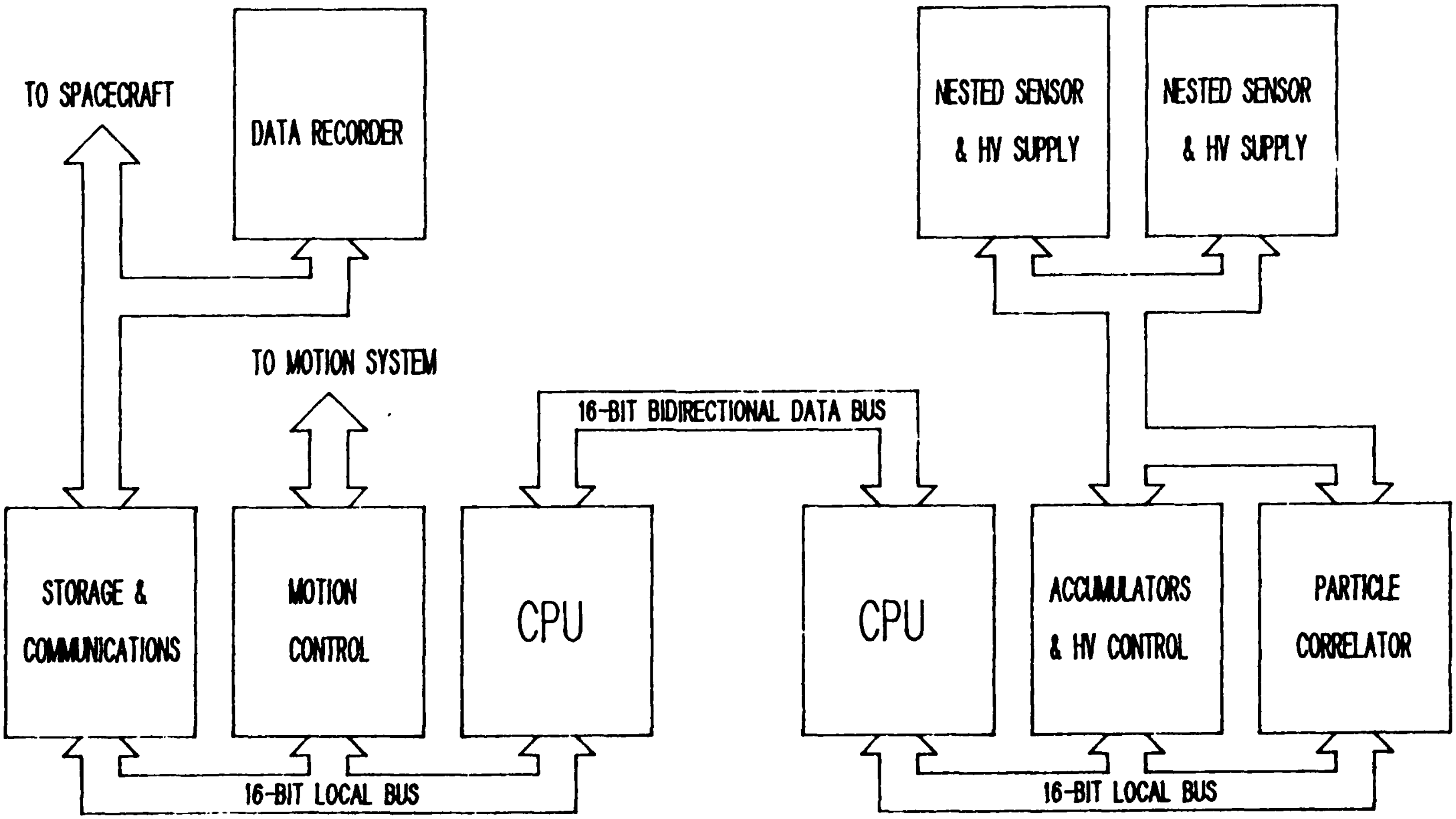
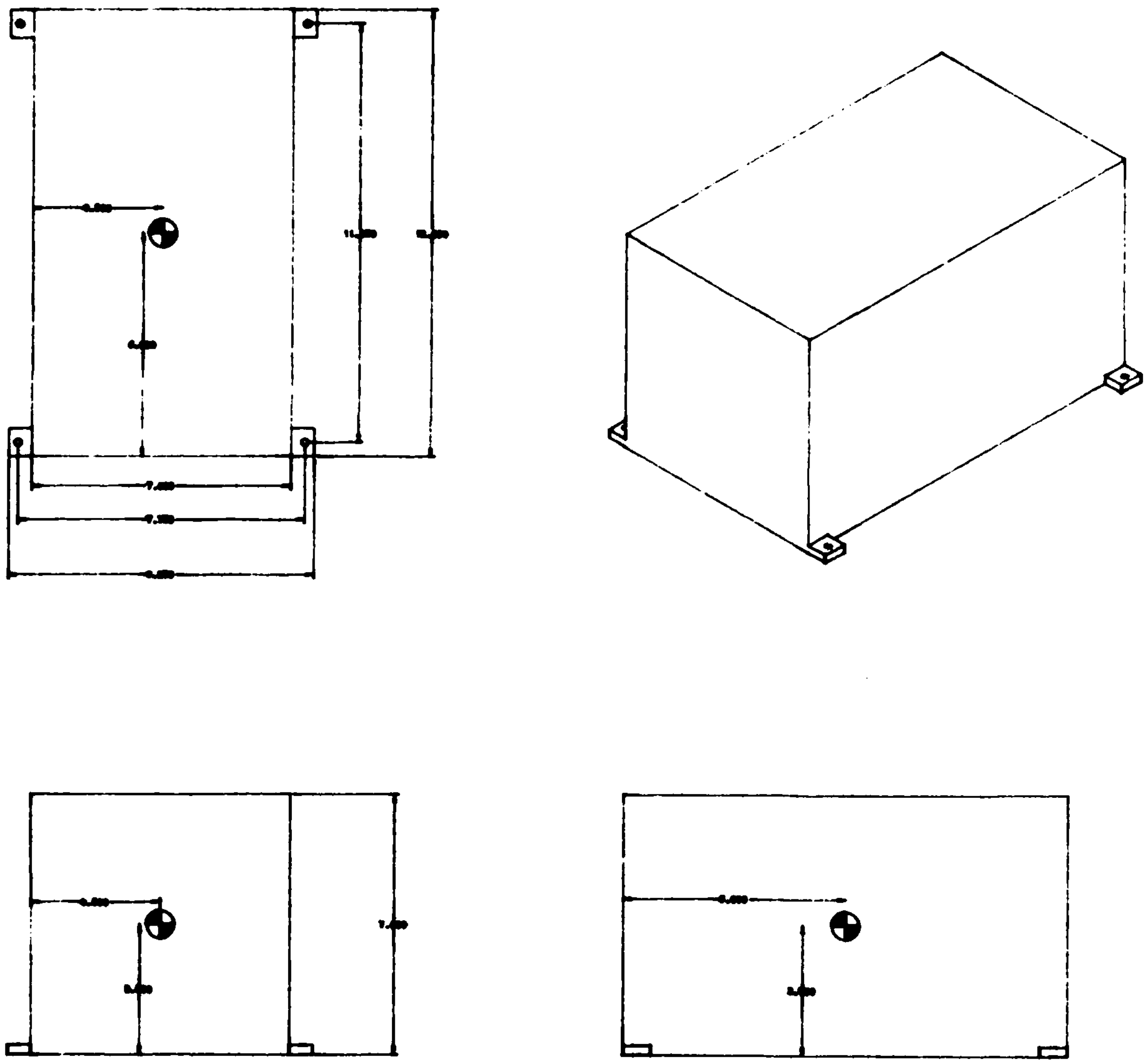



FIGURE QR1-6

Data Processing Unit



WEIGHT: 16 POUNDS

POWER DISSIPATION: 12 WATTS

FIGURE QR1-7

## High-Voltage Optocoupler

A high-voltage optocoupler is being developed for use within an instrument's high-voltage power supply. The optocoupler will perform as a current controlled current switch. Typical applications include regulating the potential between deflection plates or across a microchannel plate.

The output switch can be modeled as a 5000 volt photodiode. The input is a string of light emitting diodes (LEDs). Infra-red light generated by the LEDs causes the reverse biased photodiode to 'leak' current by the photoelectric effect. The output current ('leakage') can be controlled by the input current to the LEDs.

In practice, a 5000 volt, low-leakage photodiode does not exist. A stack of 1000 volt transistors or diodes is being proposed as an equivalent. Custom LEDs are being examined to improve light generating efficiency. The unit will be assembled into a form of hybrid circuit.

Various optical couplings are also being developed. The couplings must be able to gather and transmit a maximum amount of light as well as withstand at least a 10,000 volt isolation voltage. Parabolic reflectors, light pipes, fiber optic faceplates, and several silicone encapsulations are presently under test as such couplings.

Some goals of this development are to obtain an optocoupler that can withstand an input-output isolation voltage of 10,000 volts, hold an output differential voltage of 5000 volts, and pass 500 microamperes of output current with only 20 milliamperes of input drive current.

The following two figures show the schematic and layout of the latest design approach. This layout requires that all parts are mounted on a single piece of alumina. A silicone 'light pipe' is used for coupling. The optical path is formed by the curved shape the silicone forms due to surface tension. An outer coating of white alumina filled silicone also aids internal reflection.

This latest configuration has a light collection efficiency of 200 microamperes output for 20 milliamperes input. Output blocking voltage is initially 5000 volts, but decays after several hours. Understanding the reasons for this decay has become a top priority.

The demanding breakdown and isolation voltages will make this part unique, unlike anything available commercially. High speed and compact size are two predominate features that will improve existing high-voltage power supply designs.

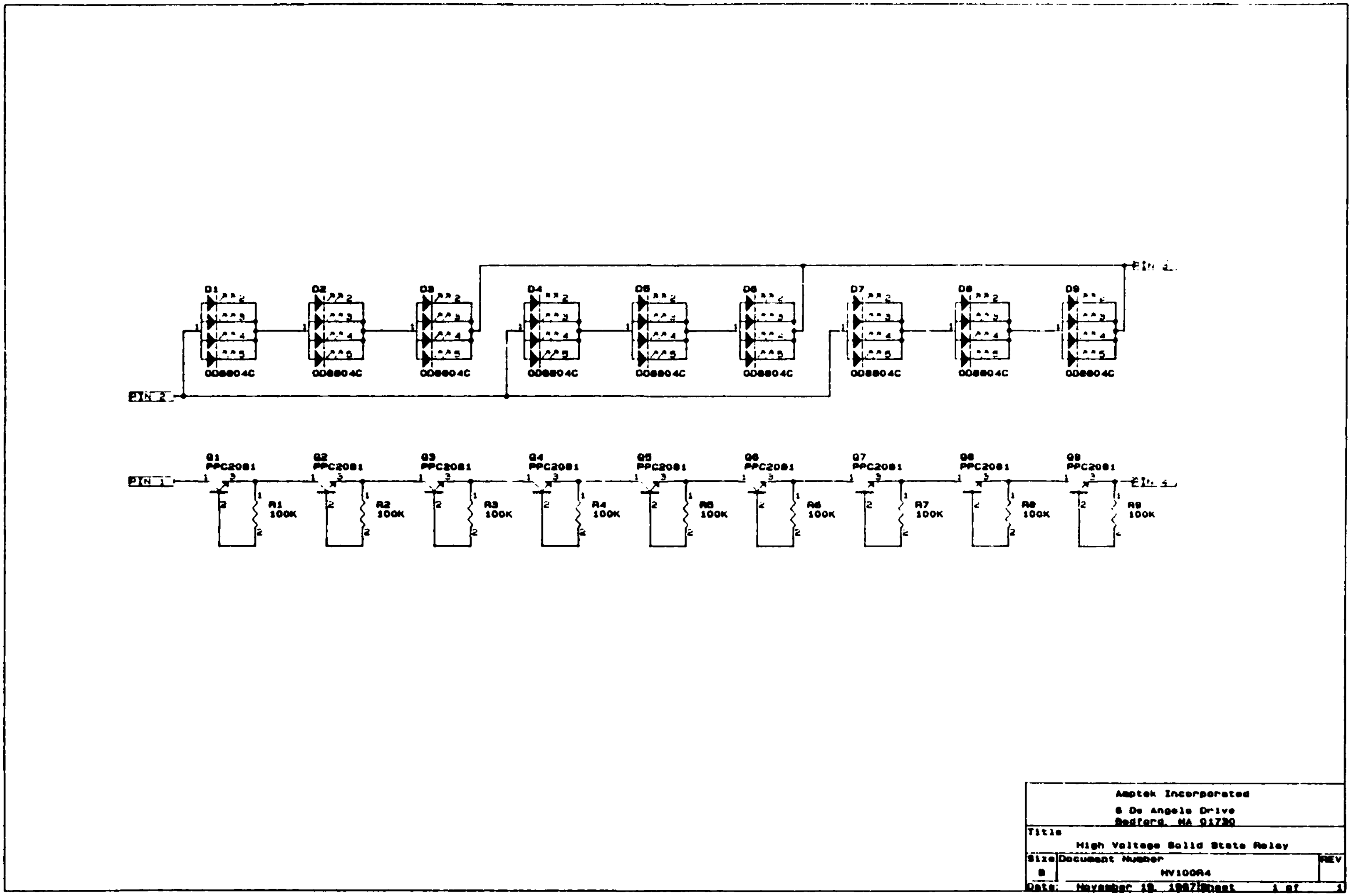

D1
D2
D3
D4
D5
D6
D7
D8
D9
OD8804C
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
PPC2081
R1
R2
R3
R4
R5
R6
R7
R8
R9
100K
PIN 1
PIN 2
Amptek Incorporated
6 De Angelo Drive
Bedford, MA 01730
Title
High Voltage Solid State Relay
Size
B
Document Number
HV100R4
REV
Date: November 18, 1987
Sheet 1 of 1

FIGURE QR1-8

NOTES:

WIRE BONDS MUST BE DRESSED TO BE NO LOWER THAN 3 MILS AND NO HIGHER THAN 5 MILS FROM ALL AREAS OF A CHIP OTHER THAN THE BONDING PAD.

WIRE BONDS MAY TOUCH THE TOP SURFACE AND EDGE OF AN L.E.D..

CONDUCTIVE EPOXY MAY NOT CREEP HIGHER THAN 20 PERCENT OF THE HEIGHT OF A CHIP, NOR MAY IT LEAVE THE TRANSISTOR PAD.

STEP AND REPEAT 1.010" X 0.410"

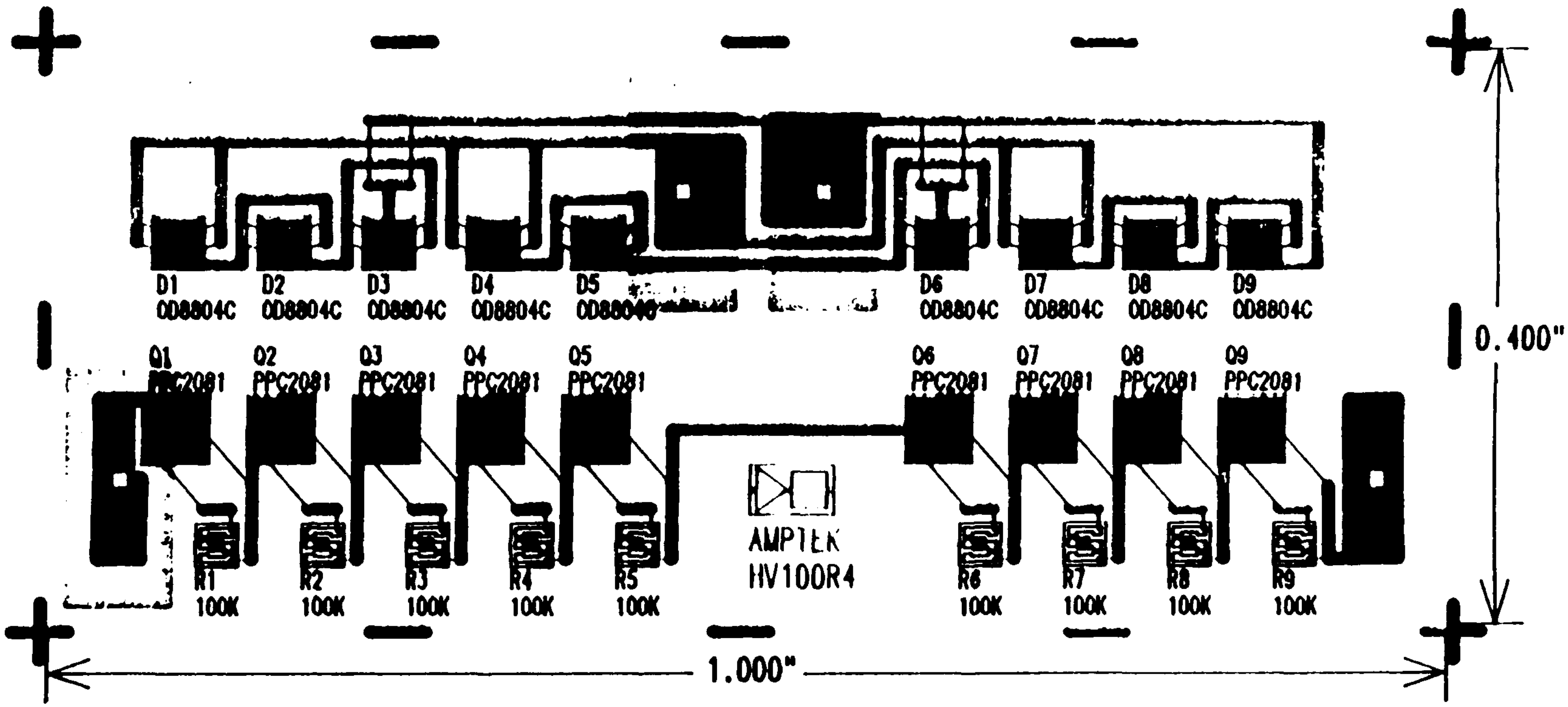



FIGURE QR1-9

PRDA-QR2

PROTOTYPE INSTRUMENTATION AND DESIGN STUDIES

AMPTEK, INC.
6 De Angelo Drive
Bedford, MA 01730

March 18, 1988

R&D status Report #2
January 1, 1988 throught March 3, 1988

Contract #F19628-87-C-0094

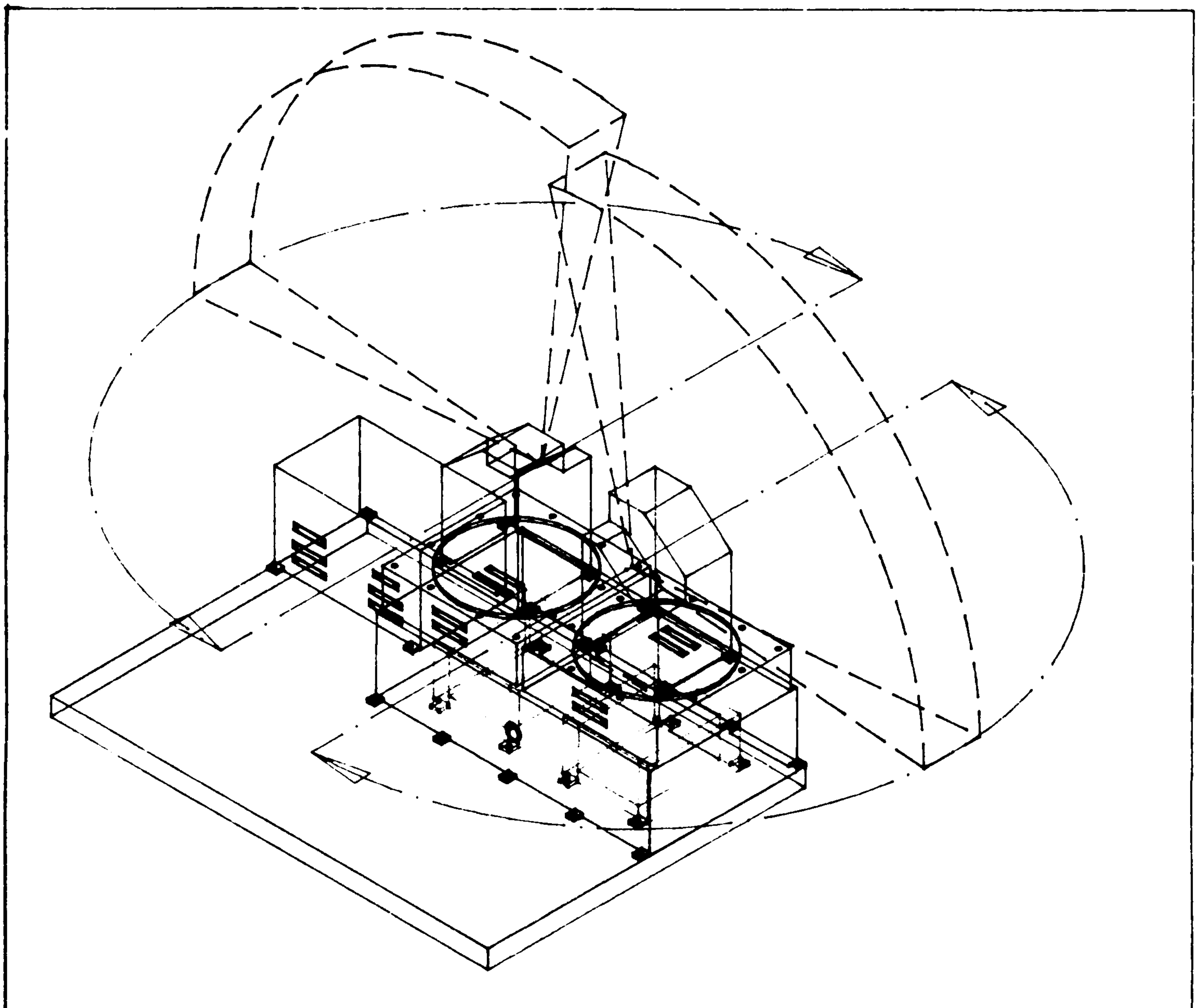
## SENSOR DESIGN

The development of a motorized nested hemispherical electrostatic analyzer results in a sensor system that can view more than two pi solid angle. Because of this enormous viewing angle, it is difficult to mount the sensor on a spacecraft such that parts of its acceptance angle will not be obscured with spacecraft structural members or adjacent experiments. Surfaces near or in the sensors field of view can effect the data either by shadowing or by charge accumulations that generate electric fields that will deflect incoming particles.

Amptek has been using computer simulations and graphics methods of modeling the sensor system and its associated fields of view. These methods allow the three dimensional modeling of surfaces and structures in the vicinity of the sensor and the identification of the degree of obscuration. This method simplifies optimizing the sensor viewing, the range and rate of mechanical sweeping, and the necessary data processing algorithms needed to interpret data sets taken while the view is obscured.

Satellite structures and sensor mounting on them can often accommodate large viewing angles, but experiments flown in the STS shuttle bay will have limited ranges of mounting possibilities. Because the shuttle bay seems to be a worst case example of limited and obscured viewing, the modeling technique was used to assess a pair of nested hemisphere ESA's mounted in the shuttle bay. Figures 1 and 2 show examples of some of these viewing problems. An experiment mounted on a pallet that is above the bay door sill will have reasonably good viewing. The principle obscuration would result from adjacent experiments and pallets.

Amptek has been discussing microchannel plate designs and configurations with a manufacturer. Figure 3 shows a possible arrangement which will allow a single shape to map both the electron and ion sensor responses. If a single shape can be developed, the cost of manufacturing the plates should be reduced and the necessary inventory of spare plates needed for future flight projects would be minimized. It is important to make an early definition the microchannel plates because they are state-of-the-art developments that have long lead times associated with their manufacture.



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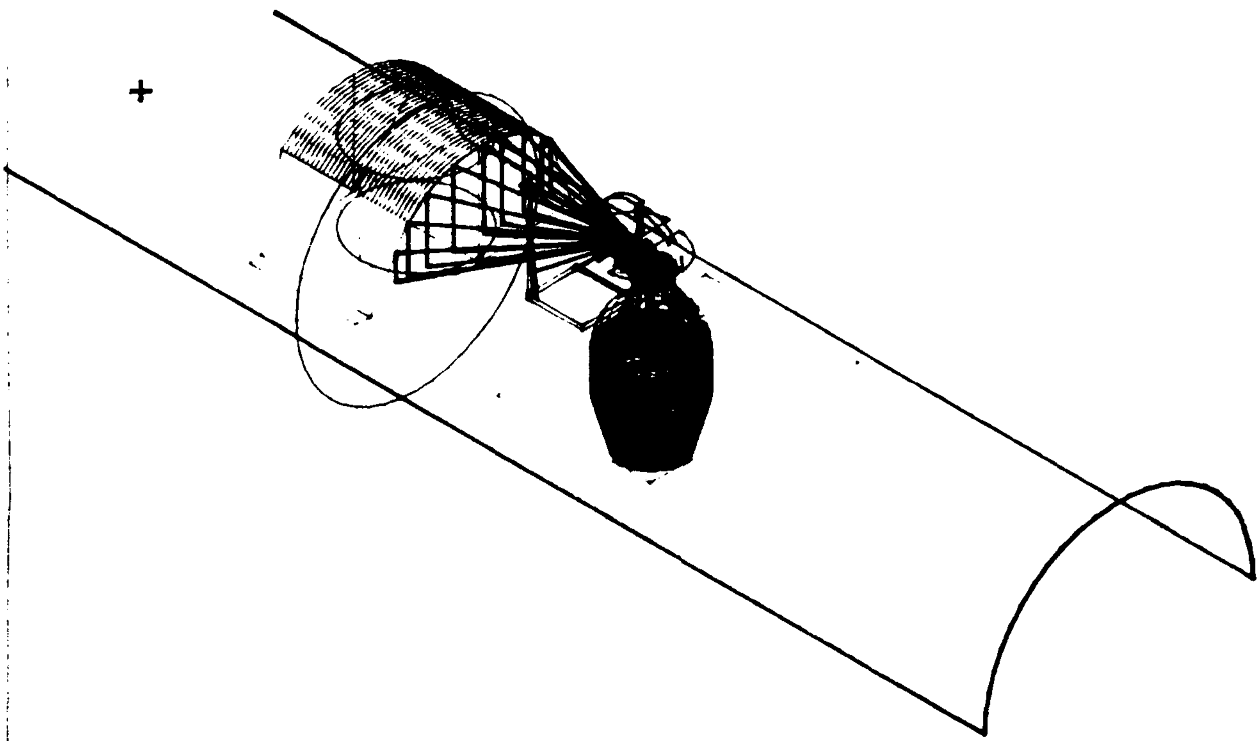
| UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES WITH TOLERANCES ON: | CHECKED | | |
| FRACTIONS ±1/32 — DECIMALS .XX ±.02 .XXX±.005 — ANGLES 0°15′ | DESIGN | | |
| | PROJECT MANAGER | | |
| MATERIAL | QUALITY ASSURANCE | | TITLE ESAs WITH ROTARY TABLES, RECORDERS, AND DPU |
| FINISH REQUIRED | PROJECT PRDA | | SIZE A |
| | CONTRACT NUMBER F19628-87-C-0094 | | SCALE — WEIGHT — SHEET OF |

FIGURE QR2-1



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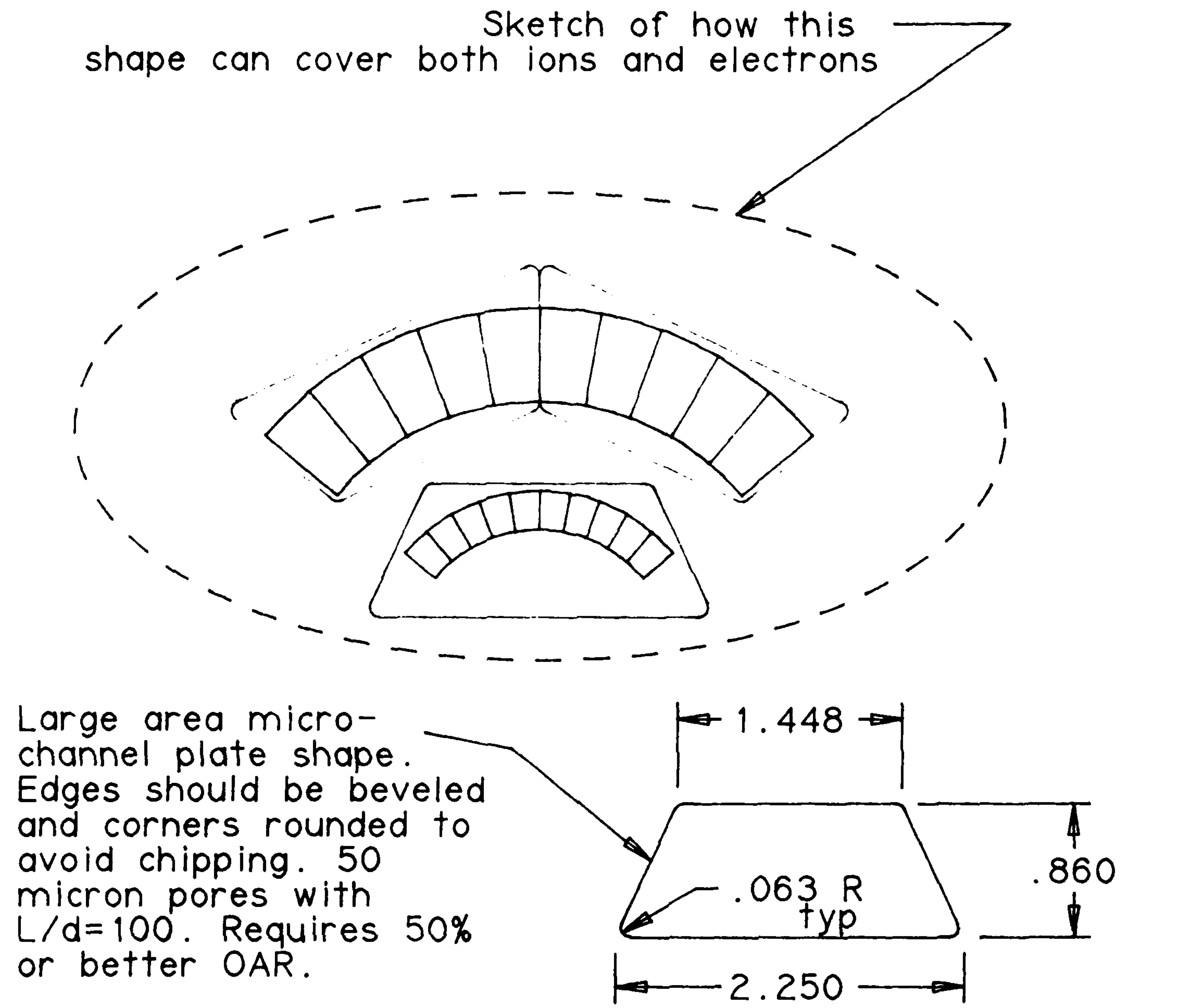
| | DESIGN | | | | |
| FRACTIONS ±1/32 DECIMALS .XX ±.02 .XXX±.005 ANGLES 0°15' | PROJECT MANAGER | | TITLE SHUTTLE CARGO BAY WITH POSSIBLE PAYLOADS AND ESAs | | |
| MATERIAL | QUALITY ASSURANCE | | | | |
| FINISH REQUIRED | PROJECT PRDA | | | SIZE A | |
| | CONTRACT NUMBER F19628-87-C-0094 | | SCALE | WEIGHT | SHEET OF |

FIGURE QR2-2

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| UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES WITH TOLERANCES ON: FRACTIONS ±1/32 DECIMALS .XX ±.02 .XXX±.005 ANGLES 0°15' | CHECKED | | | |
| | DESIGN | | | |
| | PROJECT MANAGER | | TITLE LARGE AREA MICRO-CHANNEL PLATE SKETCH | |
| MATERIAL | QUALITY ASSURANCE | | | |
| FINISH REQUIRED | PROJECT PRDA | | | SIZE A |
| | CONTRACT NUMBER F19628-87-C-0094 | | SCALE 1X | WEIGHT / SHEET OF |

**FIGURE QR2-3**

## HIGH VOLTAGE OPTOCOUPLER

The Optocoupler project is aimed at developing a small and efficient method of controlling the output stage of a high-voltage (5-10kV) source. Typical applications include biasing deflection plates.
The search for an LED emitter for the input stage has ended with a custom design. Applications for the Optocoupler will require significant light output from the LEDs for several years. Typical devices are not very efficient and would have deteriorated rapidly when driven to provide the necessary output power. The custom approach started by choosing a manufacturer with an existing high efficiency part. Modifications were made to a standard LED chip to quadruple its existing surface area. This effectively cut the strain in each junction by 75%. Degradation appears to react exponentially with strain, so the new LEDs are expected to last well over 10 years under moderate service. Prototypes have been delivered from the manufacturer. The custom LED chip is depicted in figure HV-1.

Numerous attempts have been made to obtain a stable, high voltage, high gain silicon junction for the output stage. Studies have been conducted with both diodes and transistors. The high sensitivity to contamination of high voltage devices has posed many problems. In the interest of obtaining an extremely robust optocoupler, a custom diode is also being developed. This diode design is heavily passivated with glass. It's mesa structure aids in the passivation technique and helps prevent premature 'hotspots'. The large open area on the top of the chip is optimized for IR light collection. Breakdown voltages for these devices should range from 600V to 800V, with a dark current leakage of less than 20nA. Delivery of the first prototypes is expected at the end of May, 1988. The high voltage diode chip is shown in figure HV-2.

The process of optically coupling the IR LEDs to the light sensitive region of the high voltage diodes can be approached in many ways. The most promising technique appears to be with the introduction of a fiberoptic faceplate. Figure HV-3 roughly describes a method for mounting all the critical parts together. Both the LEDs and the diodes are mounted on separate substrates and isolated by the fiberoptic glass. Fiberoptics are used to transmit the 'image' of the LEDs onto the diodes with a minimum amount of light spreading or loss. This design couples a maximum amount of light between the active devices while providing high voltage isolation. The entire assembly is potted in a high purity silicone elastomer for hermeticity and dielectric strength. Connections have been omitted for clarity.
These processes will produce a very compact regulating device, capable of efficiently controling currents at high frequencies.

# Opto Diode Custom LED OD-8804C

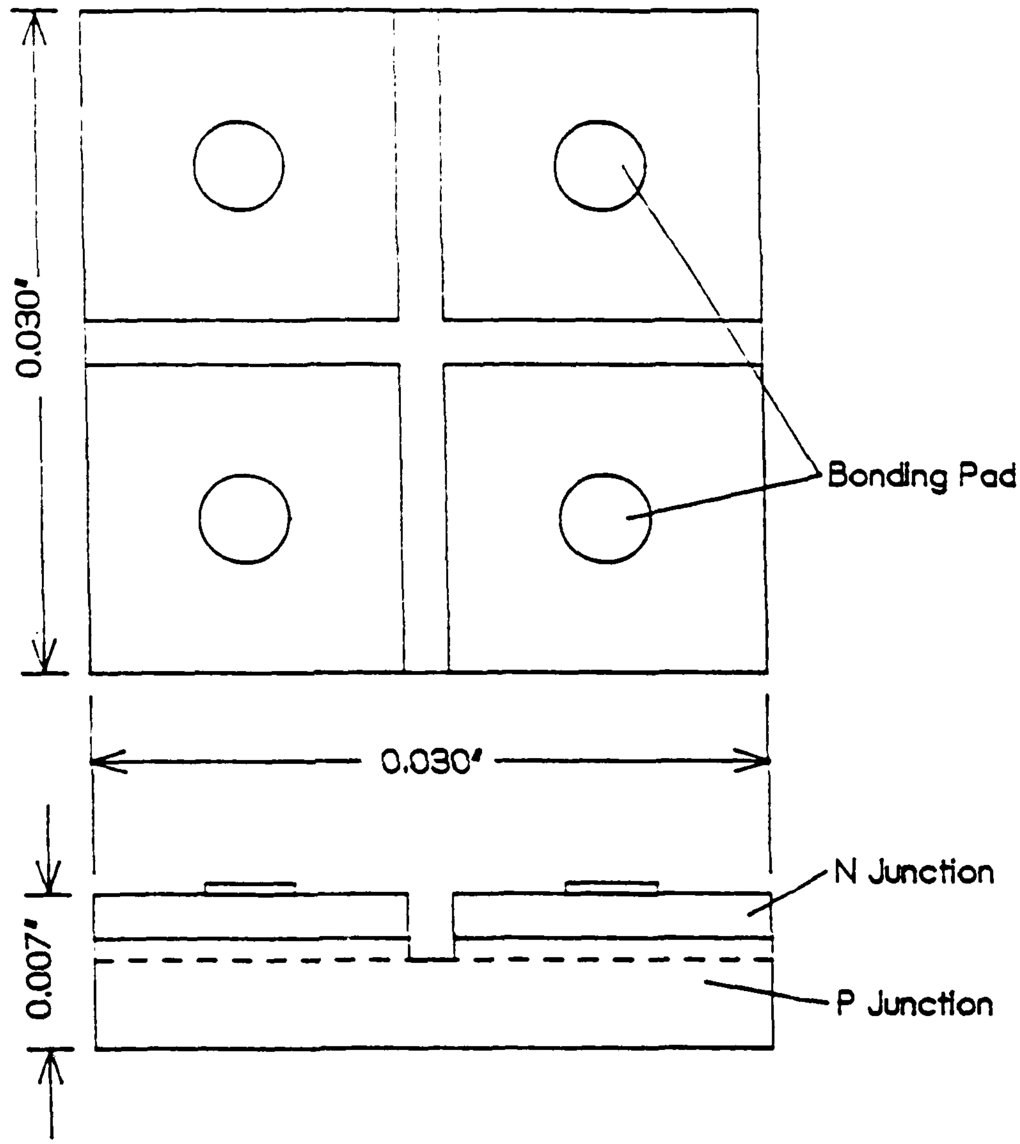
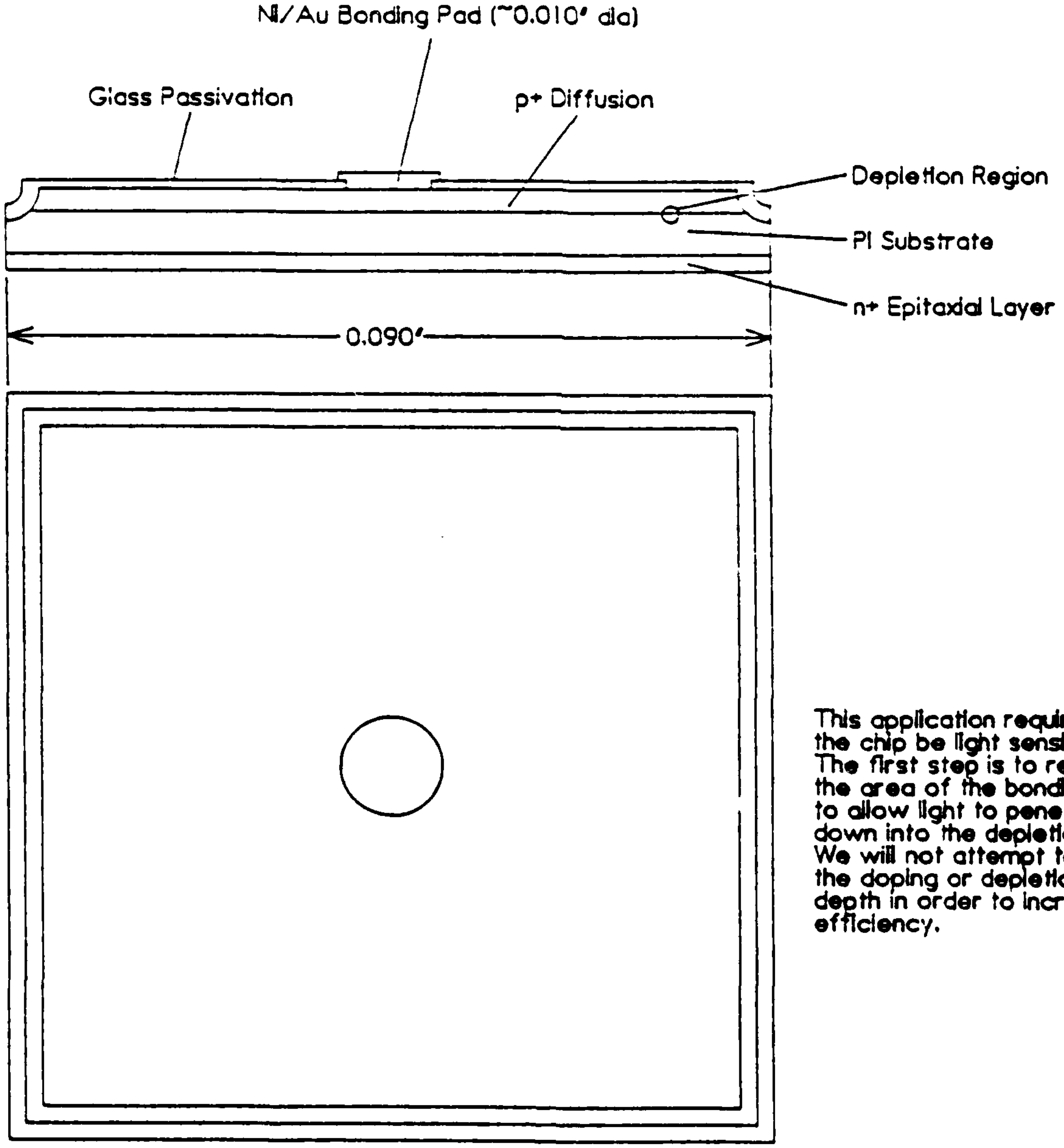



FIGURE QR2-4

Amptek part numbers:

CG3.0/6-30: Dark current < 30nA @ 600V
CG3.0/8-30: Dark current < 30nA @ 800V

## Custom Application for the CG3.0 Chip




This application requires that the chip be light sensitive. The first step is to reduce the area of the bonding pad to allow light to penetrate down into the depletion region. We will not attempt to modify the doping or depletion depth in order to increase efficiency.

FIGURE QR2-5

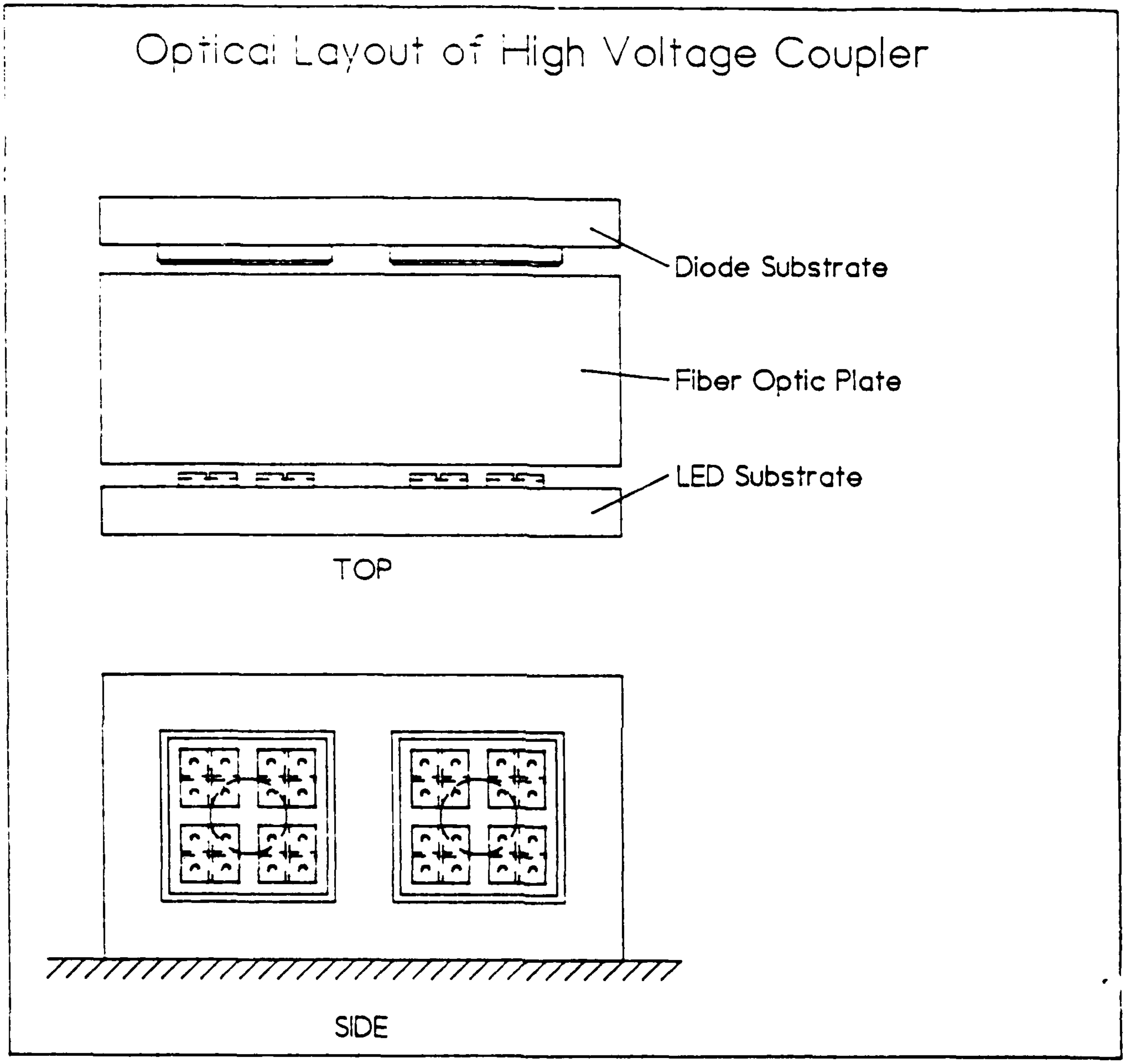

Optical Layout of High Voltage Coupler
Diode Substrate
Fiber Optic Plate
LED Substrate
TOP
SIDE

FIGURE QR2-6

## CASSETTE TAPE SUBSYSTEM

A high capacity tape drive is being developed to address the problem of acquiring massive volumes of data. Modern recoverable experiments, such as those aboard shuttle, have the opportunity and technology to generate enormous amounts of data. Particularly, imaging data. Down links via radio are often insufficient for the amount of information available. The Exabyte EXB8200 Cassette Tape Subsystem (CTS) may provide an economical solution for storing up to 2 giga bytes (2,000,000,000) of data.

The basic tape transport mechanism uses helical scanning to achieve its high density. This technique has been used for many years in analog designs such as video tape recorders (VCR). The major breakthrough with the CTS is the ability to store digital data. In theory, every dot of every picture produced by a VCR could be a digital bit. Picture dropouts and other tape errors, however, are always present and require special consideration. Extensive error correcting processes must be employed and are accomplished with several application specific integrated circuits (ASIC). The recent availability of large scale ASICs has made this system feasible for reliable digital data storage.

Presently, the CTS is being evaluated for its electrical and mechanical integrity.

Electrical tests will determine the reliability of the stored data and thus suggest appropriate applications. Initial results indicate that the CTS can at least hold imaging data, where an occasional bit error would go relatively unnoticed. A more stringent requirement would be to store processor instruction codes. The feasibility of this application has yet to be determined.

Mechanically, the tape transport mechanism is quite complex. Tests of it's response to a vibration input have been planned. Barry Controls Corp. has also been contacted to help with a vibration mount, if required. Enclosing the entire unit within a hermetic enclosure is planned.

If tests prove successful and a suitable enclosure and data link can be provided, the CTS will be a most desirable storage warehouse for recoverable experiments.

## Product Description

The EXB-8200 CTS, shown in FigureQR2-7 consists of an 8mm tape transport mechanism and recording channel, servo, formatter, controller, interface electronics, software, and package parts designed and produced by EXABYTE. The product is a true digital data storage device, derived from 8mm video recording technology, with performance improvements and many additional functions necessary for data processing purposes.

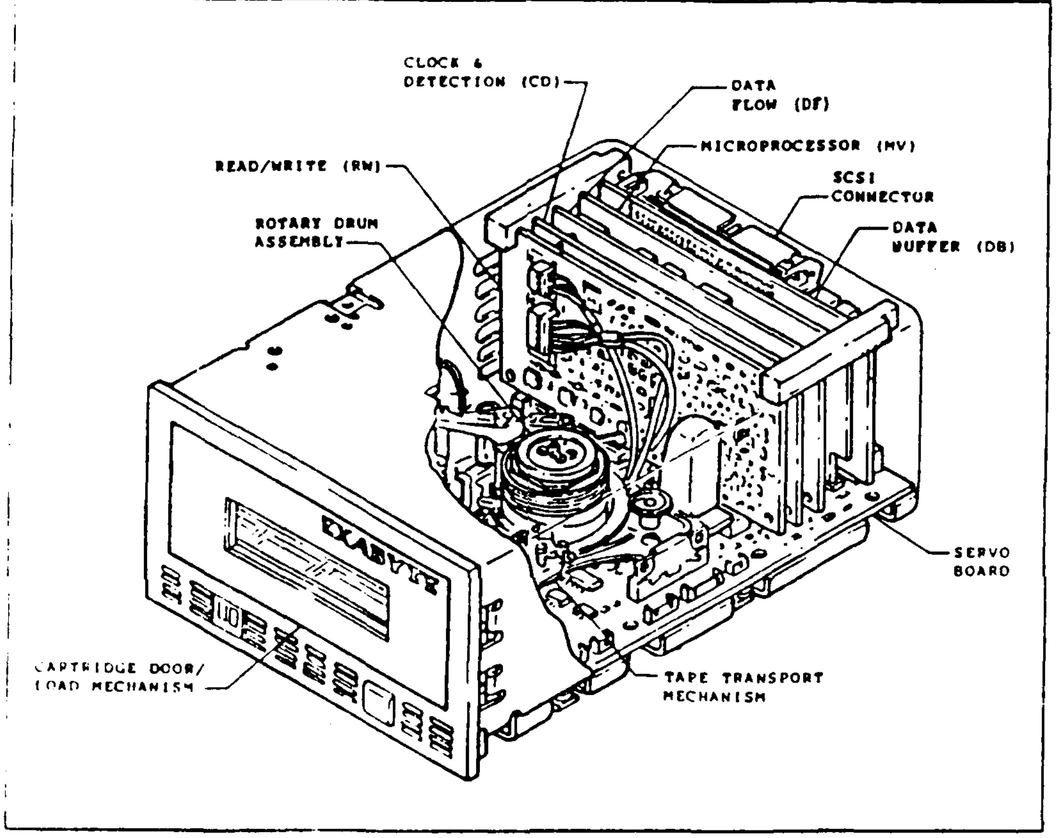



**FIGURE QR2-7EXB-8200 Cartridge Tape Subsystem**

PRDA-QR3

# PROTOTYPE INSTRUMENTATION AND DESIGN STUDIES

AMPTEK, INC.
6 De Angelo Drive
Bedford, MA 01730

June 20, 1988

R&D status Report No. 3
March 5, 1988 through June 4, 1988

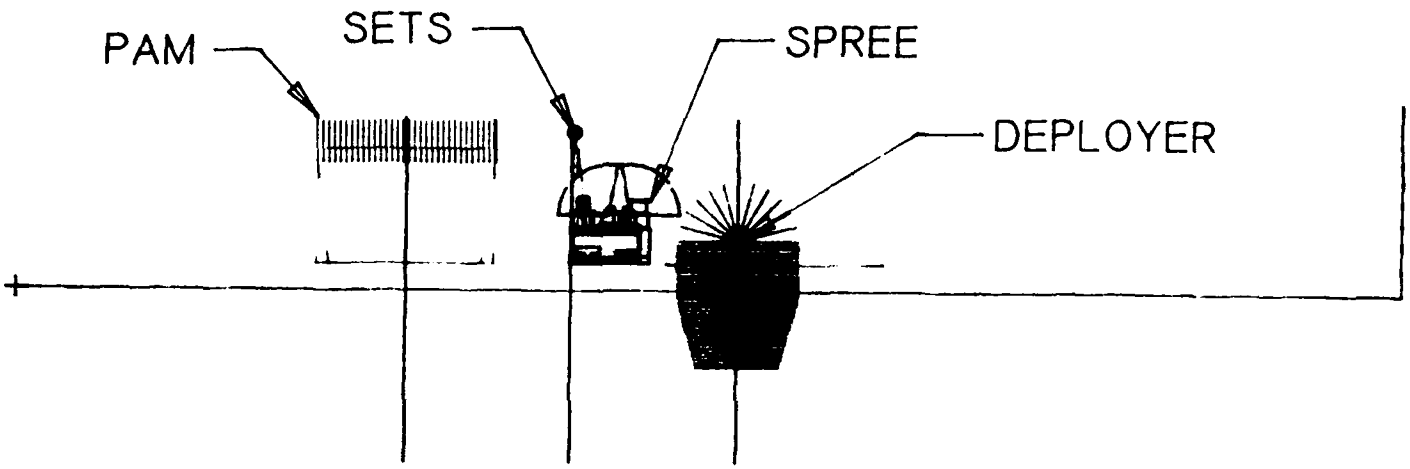
Contract #F19628-87-C-0094

## Sensor Design

The feasibility of a nested tri-quadraspheric electrostatic analyzer continues to be studied. An entire instrument complement necessary to control and archive measurements is being considered. This approach is necessary in order to utilize the vast scope of possible measurements that may be made by this type of detector array. The accompanying drawings show the current state of these support components and their possible use on a shuttle mission.

Preliminary thermal analysis of the instrument compliment indicate the need for thermal blankets and possibly heaters to maintain the orbital thermal excursions to acceptable levels for the on board electronics. Preliminary vibration analysis is being used to further the sensor and support components design. Particular attention is being paid to the mounting and electrical isolation of the spherical deflection plates and the delicate micro-channel plate electron multipliers.

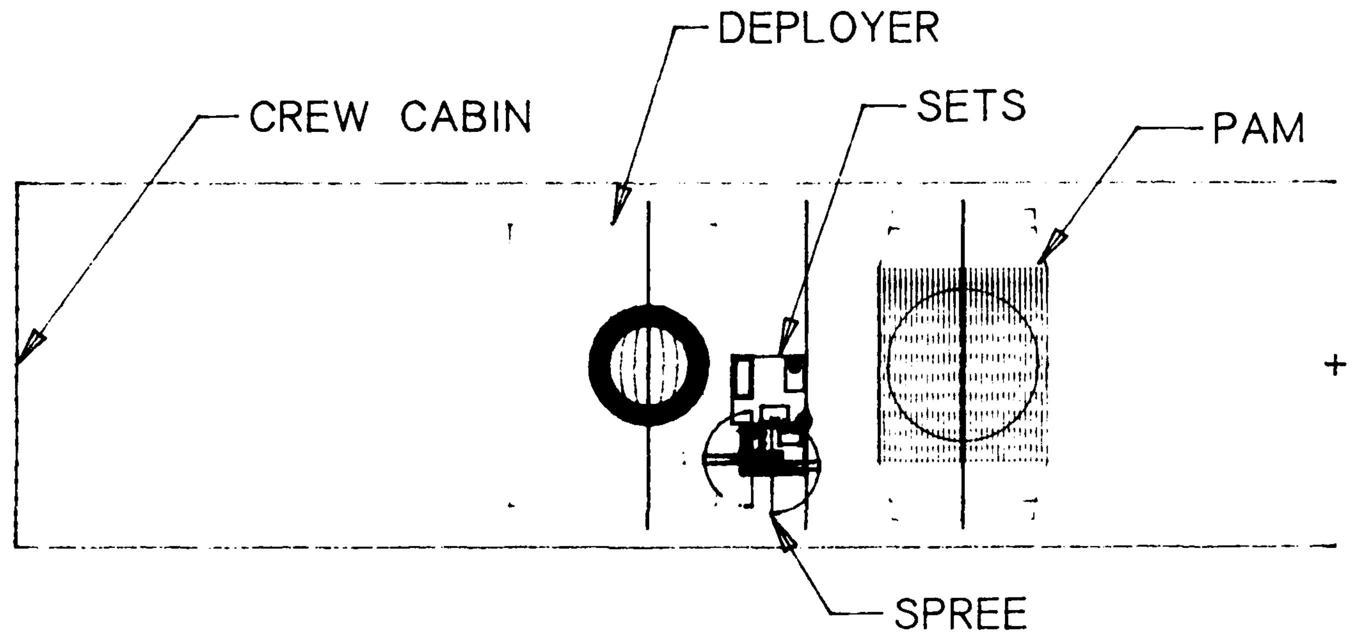
Work has begun on upgrading the vacuum chamber for the testing of the nested hemispheres. A thermal shroud has been designed, ordered, and is being installed to improve the space simulation capabilities of the chamber. A small electron gun has been built and tested. It operated from a ultra-violet light source used to illuminate an aluminum photo-cathode. The resulting secondary electrons were accelerated to form a mono-energetic electron beam. The systems worked quite well, but failed when operated continuously for a few days. The UV lamp overheated in the vacuum and generated large quantities of outgassing and contamination. Alternate electron sources as well as ion sources are being considered. Methods of beam density modulation are also being studied to allow dynamic testing of a particle correlator design.




SIDE VIEW OF SHUTTLE BAY

**FIGURE QR3-1**

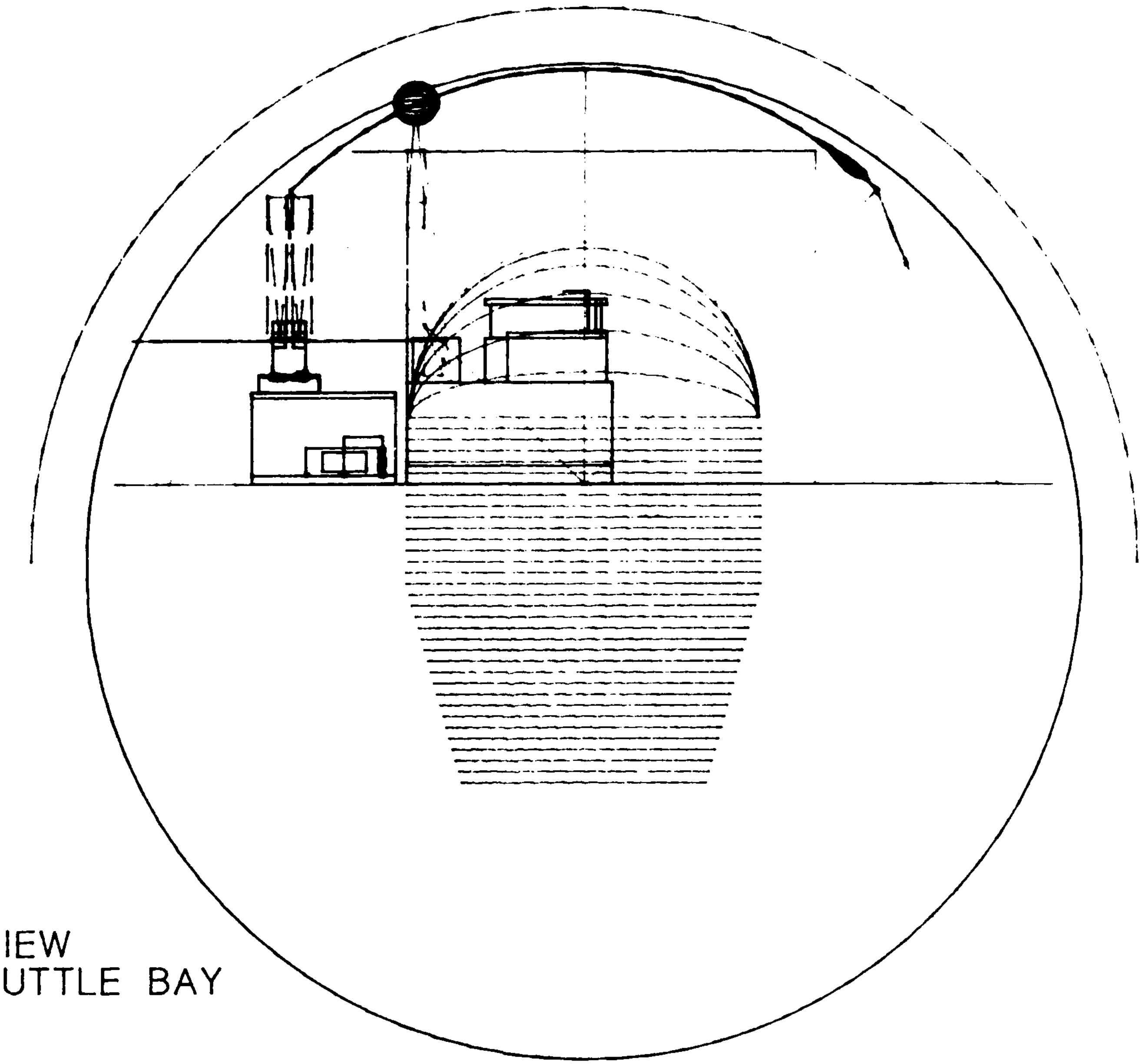
| Project No.F19628-87-C-0094 | Date: 4-28-88 | Dwg. No. D: \SPREE\SIDEVIEW.DRW |
|---|---|---|




TOP VIEW OF SHUTTLE BAY

**FIGURE QR3-2**

| Project No. F19628-87-C-0094 | Date: 4-28-88 | Dwg. No. D:\SPREE\TOPVIEW.DRW |
|---|---|---|



END VIEW
OF SHUTTLE BAY

FIGURE QR3-3

| Project No. F19628-87-C-0094 | Date: 4-28-88 | Dwg. No. D:\SPREE\ENDVIEW.DRW |
|---|---|---|

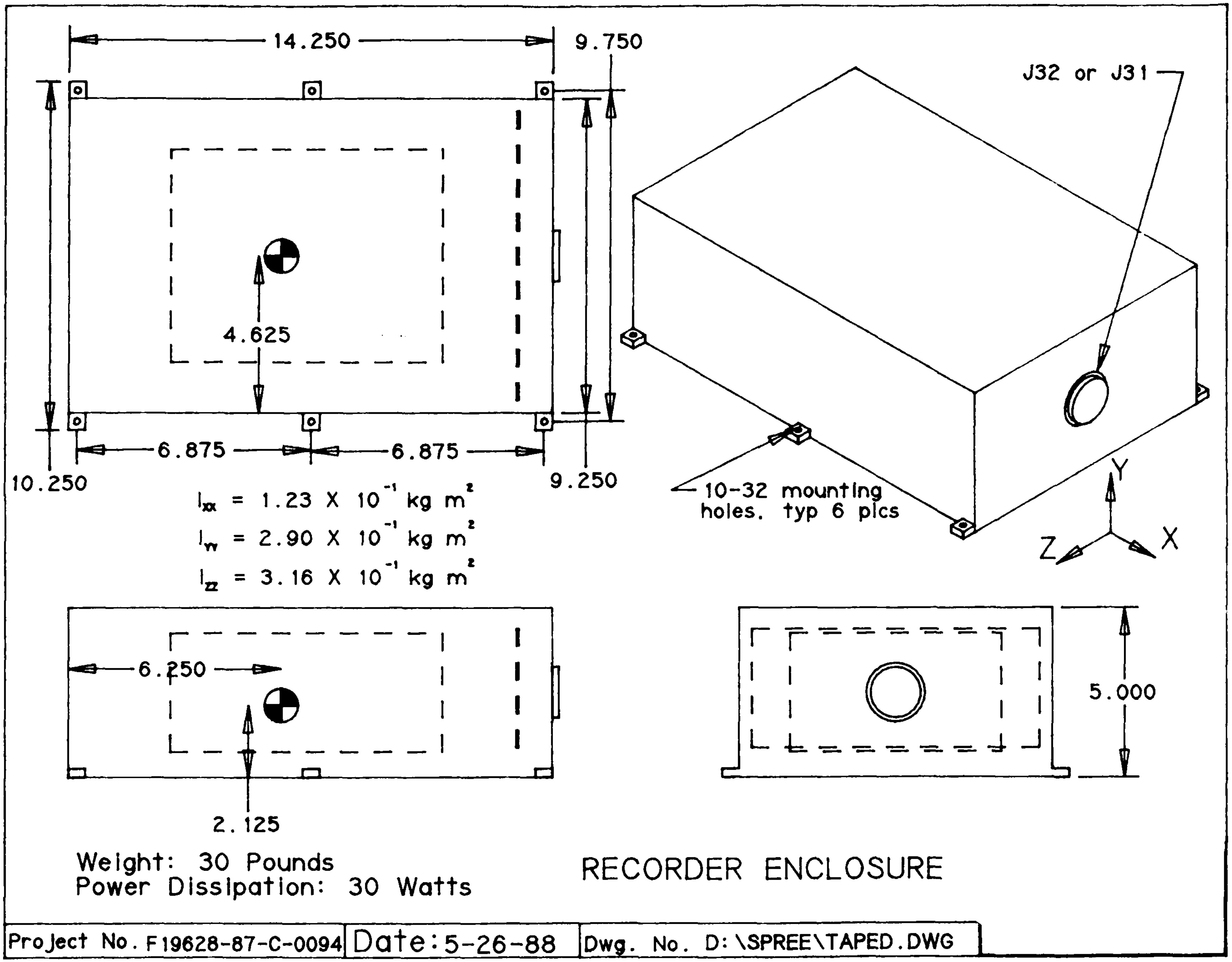

14.250
9.750
J32 or J31
4.625
6.875
6.875
10.250
9.250
10-32 mounting holes. typ 6 plcs
Y
Z
X
$I_{xx}$ = 1.23 X $10^{-1}$ kg $m^2$
$I_{yy}$ = 2.90 X $10^{-1}$ kg $m^2$
$I_{zz}$ = 3.16 X $10^{-1}$ kg $m^2$
6.250
5.000
2.125
Weight: 30 Pounds
Power Dissipation: 30 Watts
RECORDER ENCLOSURE
Project No. F19628-87-C-0094
Date: 5-26-88
Dwg. No. D:\SPREE\TAPED.DWG

FIGURE QR3-4

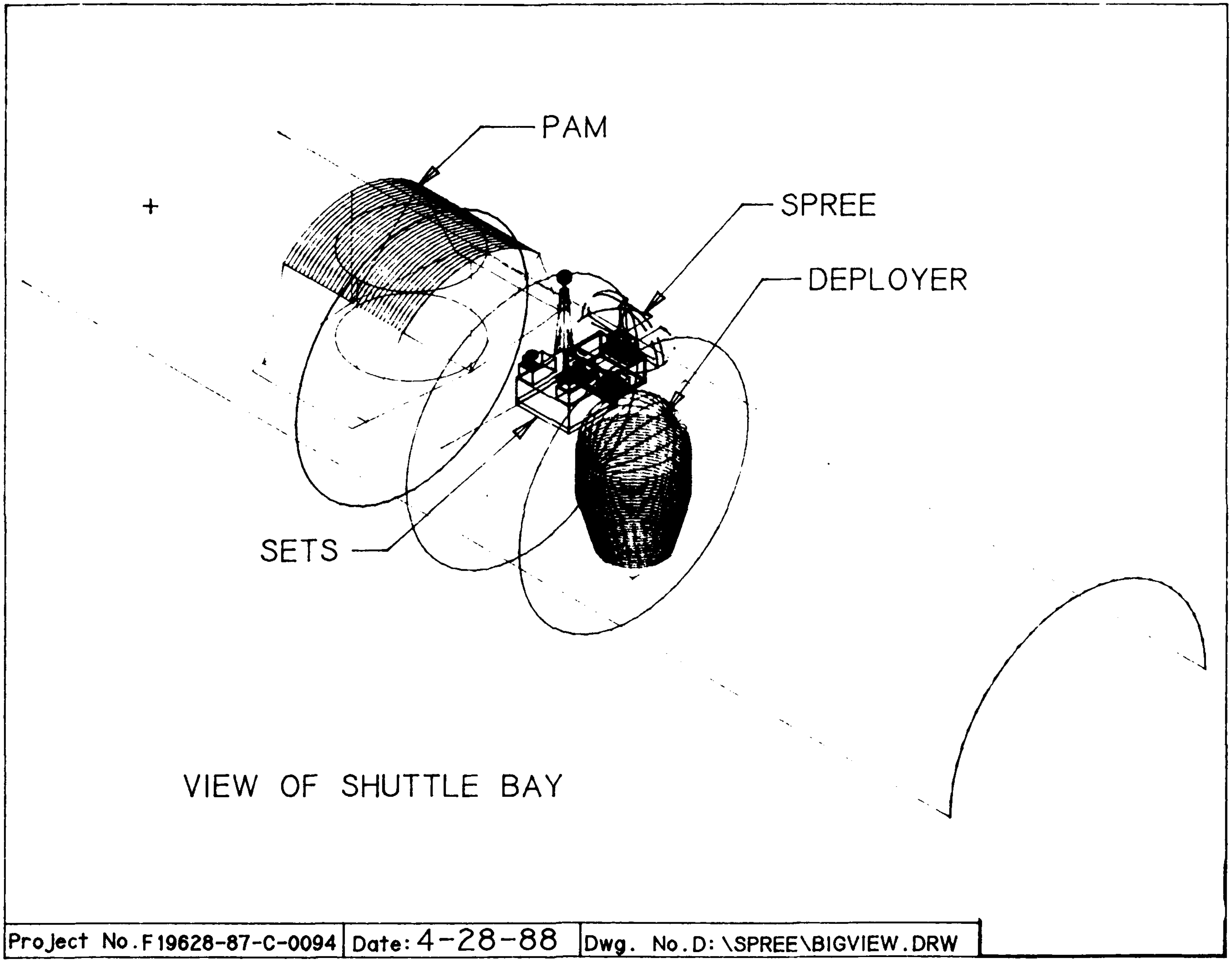

PAM
SPREE
DEPLOYER
SETS
VIEW OF SHUTTLE BAY
Project No.F19628-87-C-0094
Date: 4-28-88
Dwg. No.D: \SPREE\BIGVIEW.DRW

FIGURE QR3-5

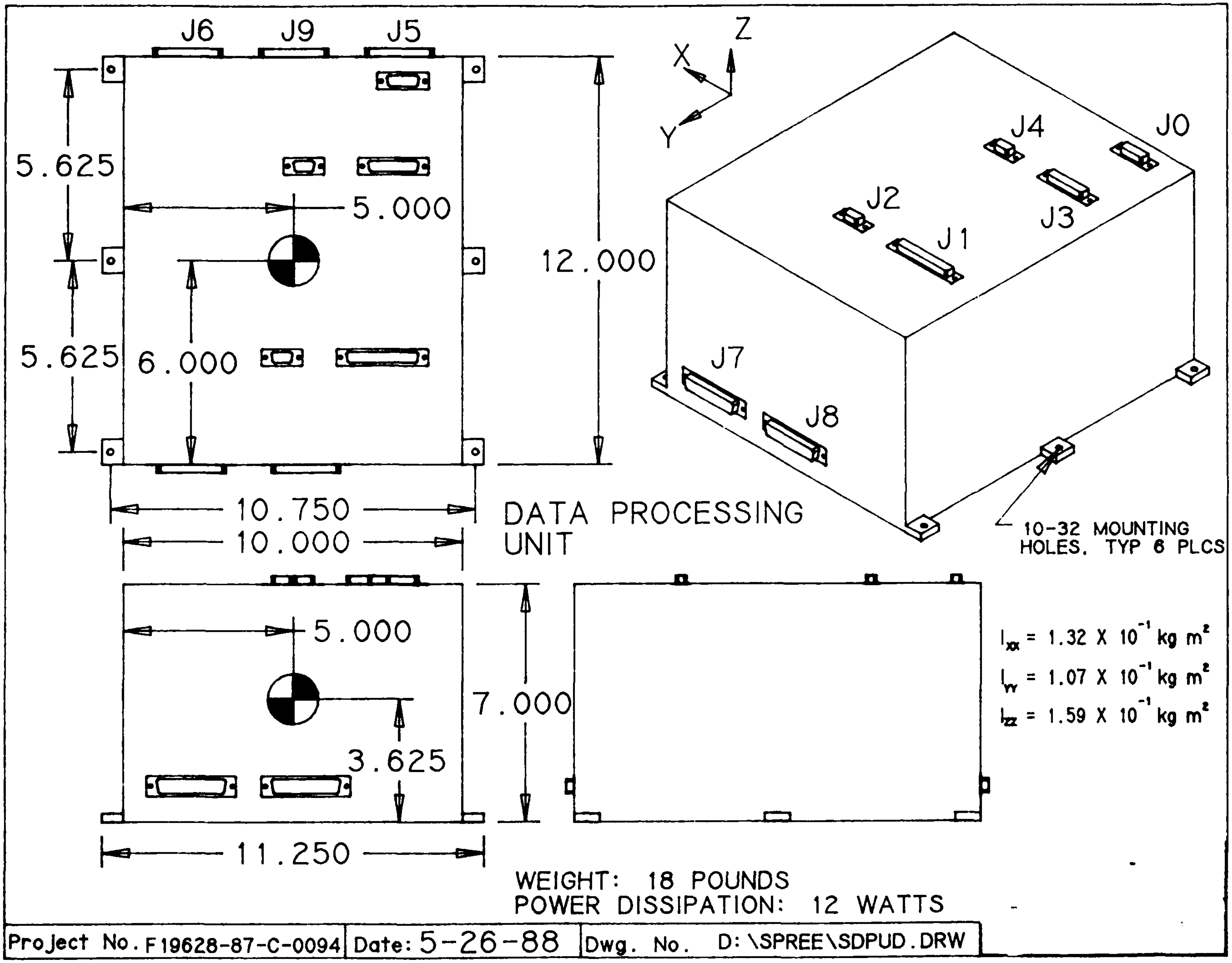

J6
J9
J5
Z
X
Y
J4
J0
J2
J3
J1
J7
J8
5.625
5.625
5.000
6.000
12.000
10.750
10.000
DATA PROCESSING UNIT
10-32 MOUNTING HOLES, TYP 6 PLCS
5.000
3.625
7.000
11.250
$I_{xx} = 1.32 \times 10^{-1}$ kg m$^2$
$I_{yy} = 1.07 \times 10^{-1}$ kg m$^2$
$I_{zz} = 1.59 \times 10^{-1}$ kg m$^2$
WEIGHT: 18 POUNDS
POWER DISSIPATION: 12 WATTS
Project No. F19628-87-C-0094
Date: 5-26-88
Dwg. No. D:\SPREE\SDPUD.DRW

FIGURE QR3-6

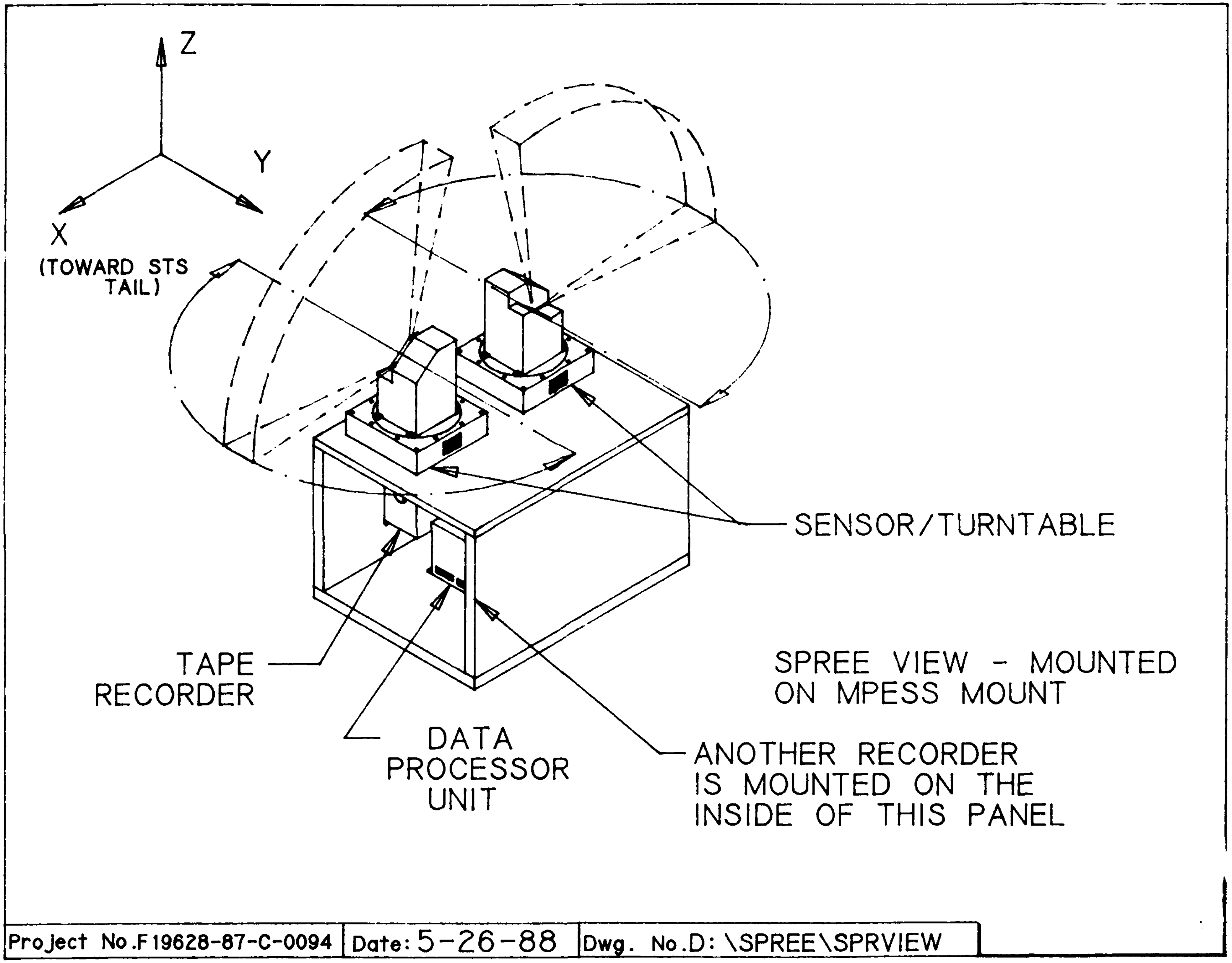
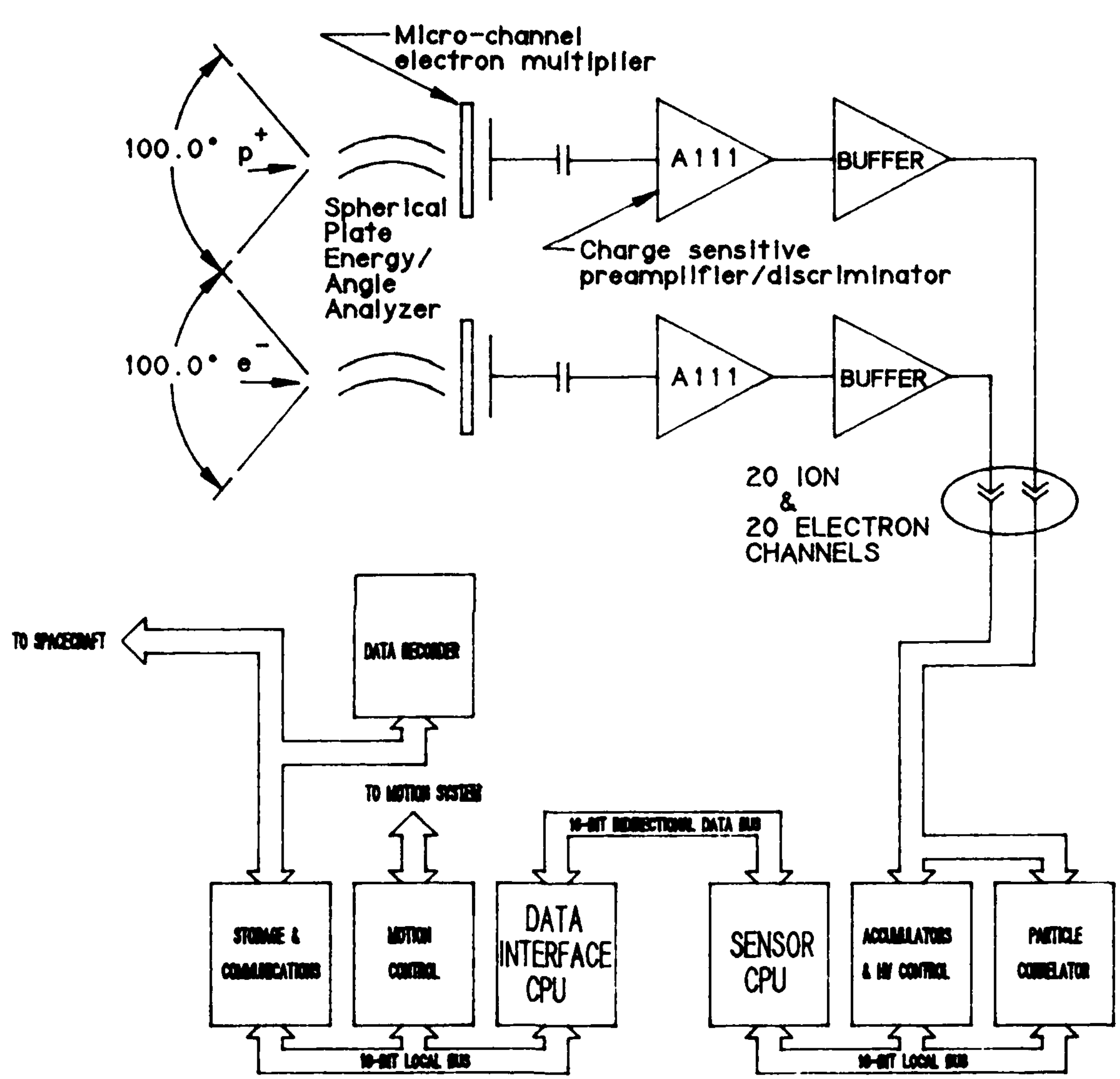

Z
Y
X
(TOWARD STS TAIL)
SENSOR/TURNTABLE
TAPE RECORDER
DATA PROCESSOR UNIT
ANOTHER RECORDER IS MOUNTED ON THE INSIDE OF THIS PANEL
SPREE VIEW - MOUNTED ON MPESS MOUNT
Project No.F19628-87-C-0094
Date: 5-26-88
Dwg. No.D: \SPREE\SPRVIEW

FIGURE QR3-7




| Project No.F19628-87-C-0094 | Date: 4-28-88 | Dwg. No.D: \SPREE\SPRDIAD |
|---|---|---|

FIGURE QR3-8

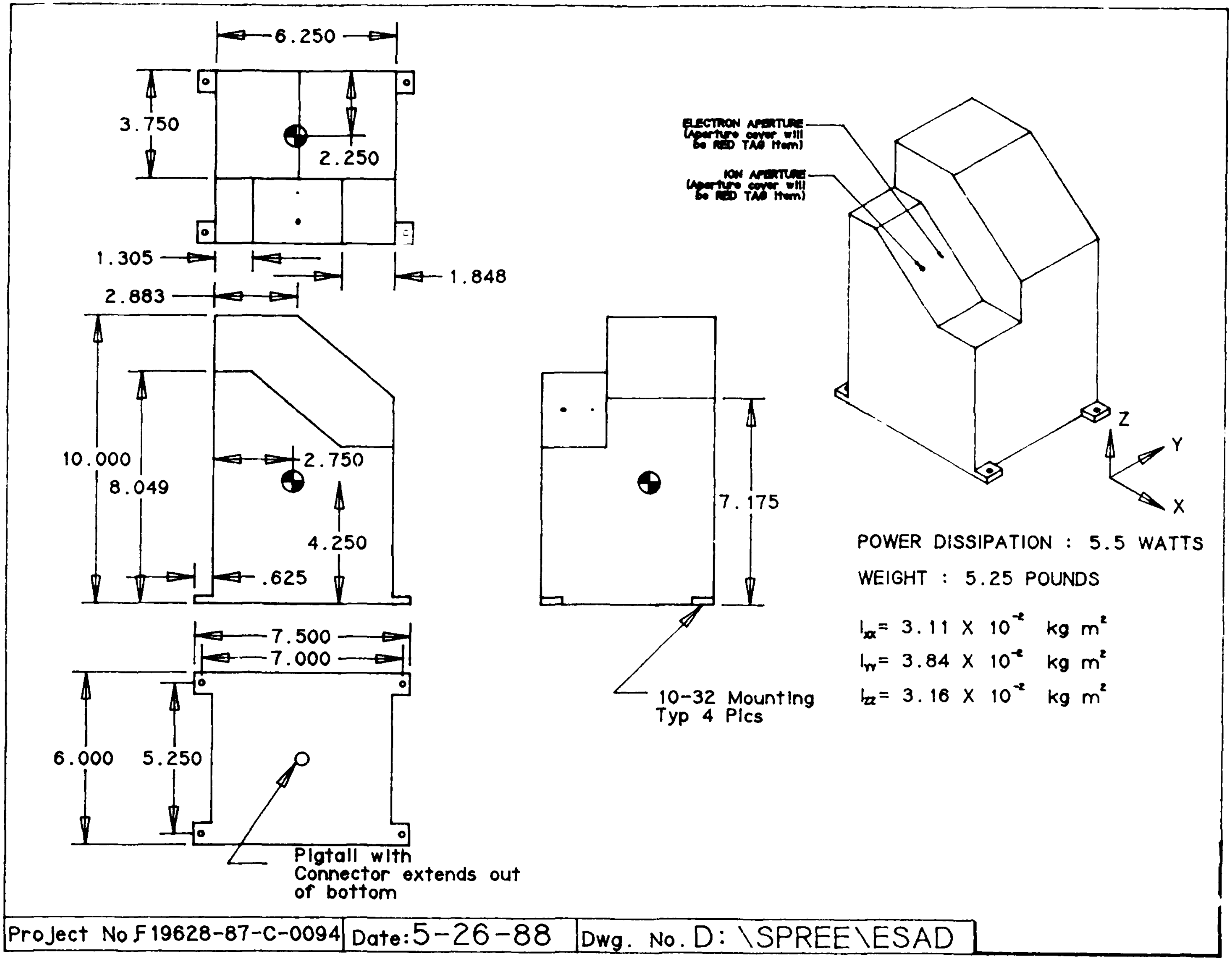

6.250
3.750
2.250
1.305
1.848
2.883
10.000
8.049
2.750
4.250
.625
7.500
7.000
6.000
5.250
Pigtail with Connector extends out of bottom
7.175
10-32 Mounting Typ 4 Plcs
ELECTRON APERTURE (Aperture cover will be RED TAG Item)
ION APERTURE (Aperture cover will be RED TAG Item)
Z
Y
X
POWER DISSIPATION : 5.5 WATTS
WEIGHT : 5.25 POUNDS
$I_{xx} = 3.11 \times 10^{-2}$ kg $m^2$
$I_{yy} = 3.84 \times 10^{-2}$ kg $m^2$
$I_{zz} = 3.16 \times 10^{-2}$ kg $m^2$
Project No F19628-87-C-0094
Date: 5-26-88
Dwg. No. D: \SPREE\ESAD

FIGURE QR3-9

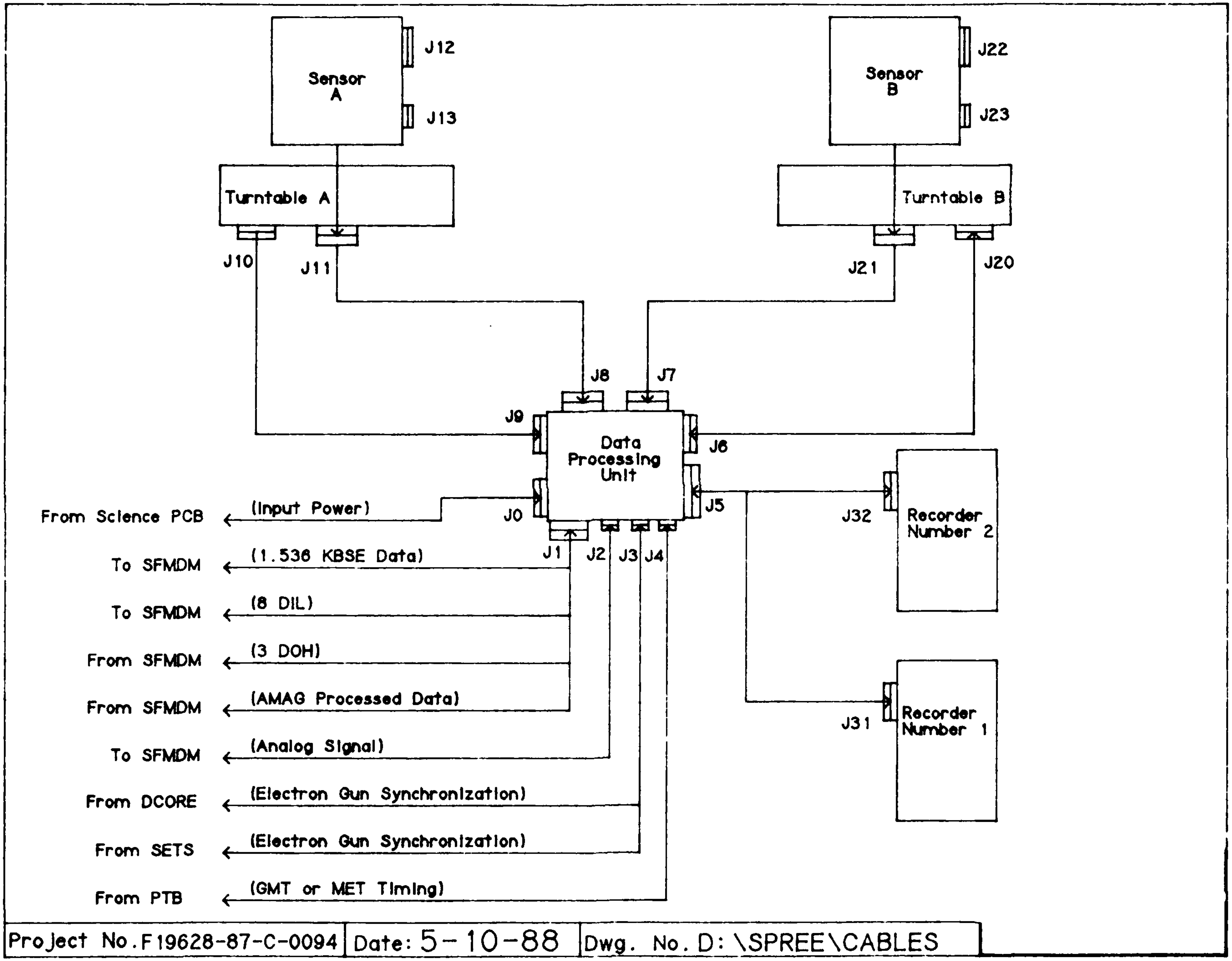



FIGURE QR3-10

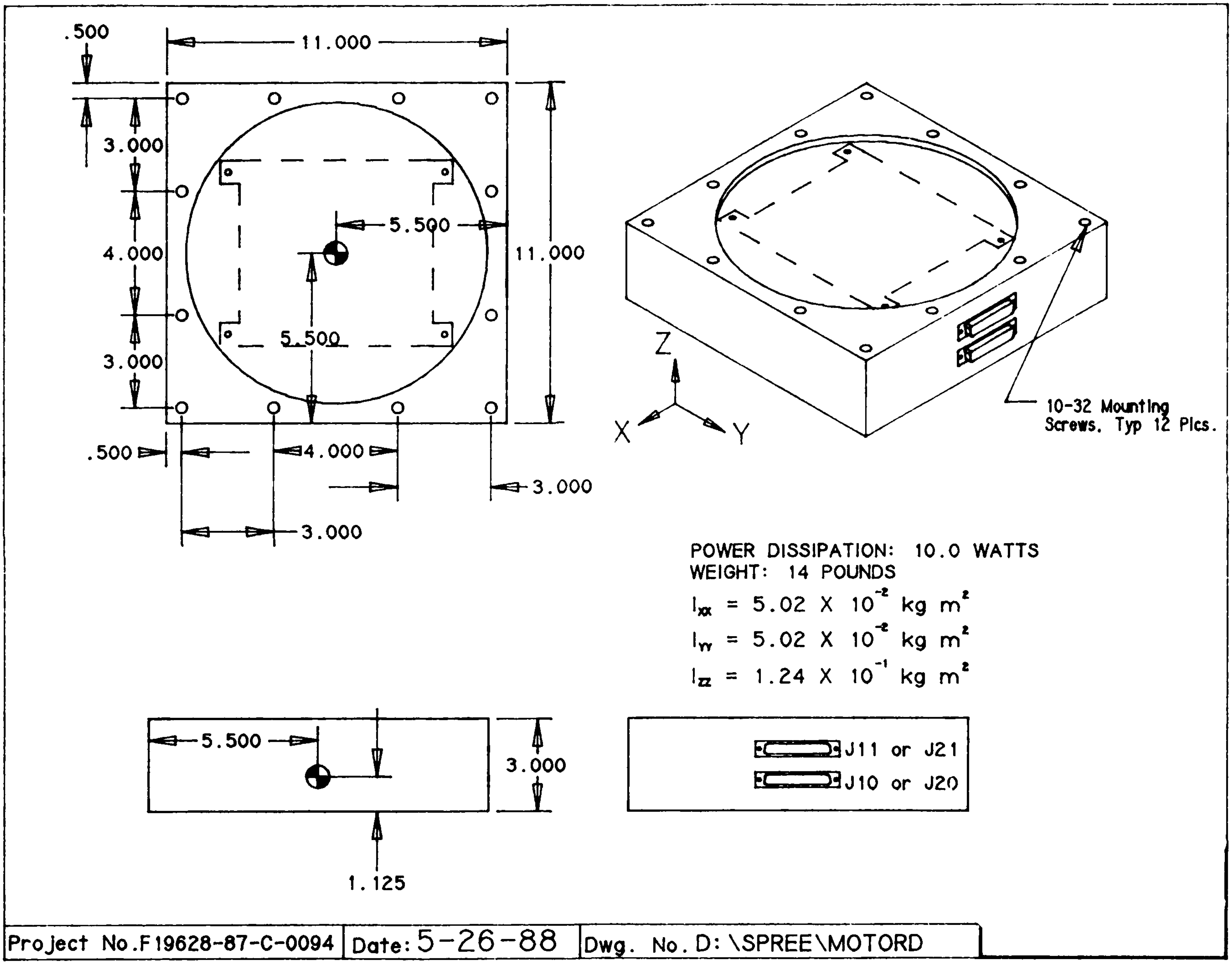



FIGURE QR3-11

## DATA PROCESSING UNIT FOR 270 DEGREE NESTED SENSORS

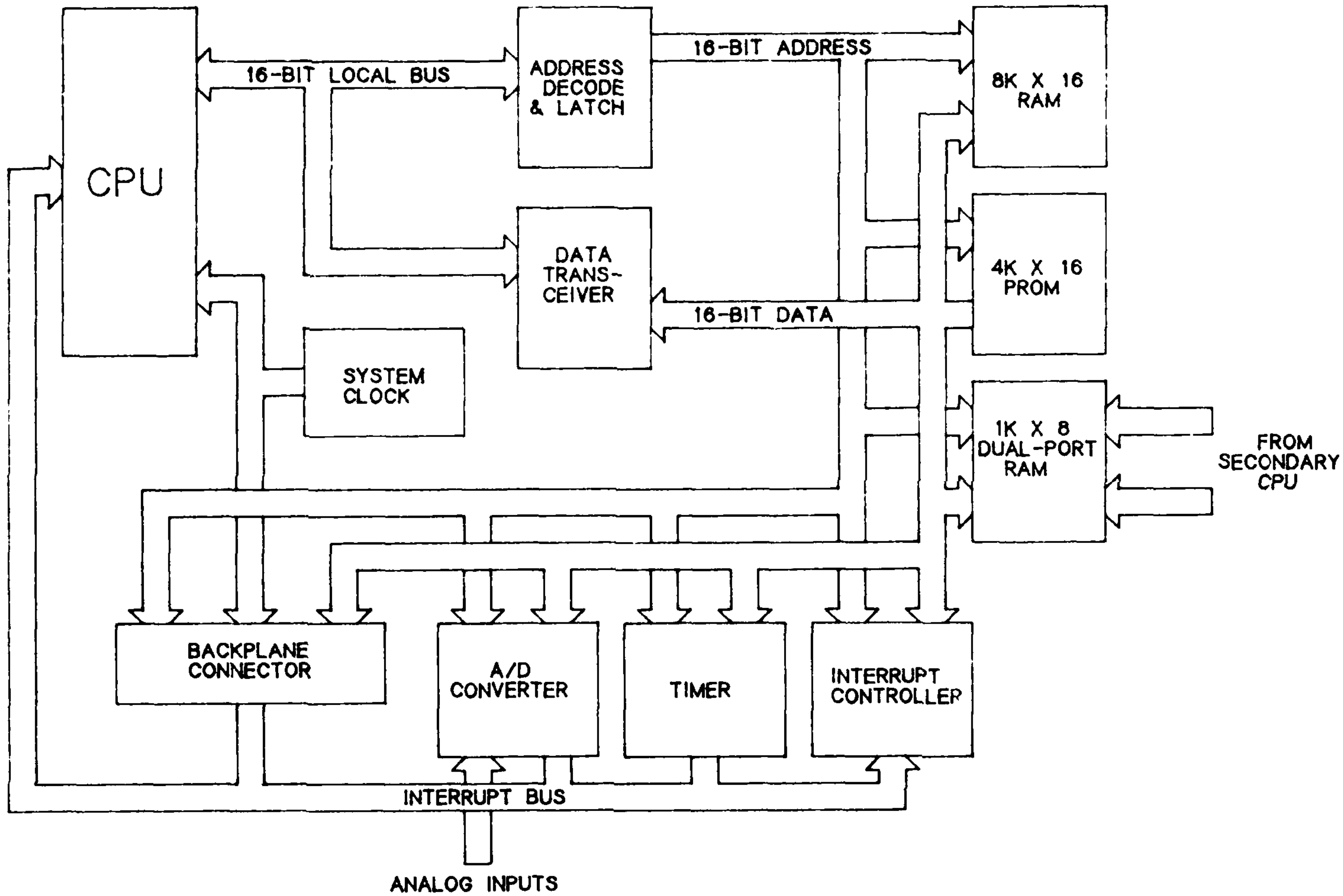
Part selection for the Data Processing Unit is nearly complete. The 80C86 microprocessor family from Harris is being used, along with HM65642 and HM6617 memory devices, also from Harris. The D400 from Amptek is being used for the 16-bit accumulators, and an analog-to-digital convertor (ADC) from PMI will be used for housekeeping information. All logic integrated circuits will come from Texas Instruments.

The design of the processor boards and the accumulator board is also nearly complete. After the operation of the memory decoding system is verified, the layout of printed circuit boards will begin.

Part selection is now under consideration for the Particle Correlator. Several microprocessor families are under consideration, including the Inmos Transputer, the Harris 80C286 with an 80287, and the combination of a Harris 80C86 with a high-speed math coprocessor.

DPU components which have not yet been designed include the particle correlator, the motion control interface, the high-voltage control interface, the spacecraft communications interface, and the power supply.

# SPREE CPU BLOCK DIAGRAM




| Project No. F19628-87-C-0094 | Date: 4-28-88 | Dwg. No. D:\SPREE\QTR1D |
|---|---|---|

**FIGURE QR3-12**

SPREE FLIGHT RECORDER

## I. Introduction

The proposed Shuttle Potential and Return Electron Experiment (SPREE) will generate enough data to mandate a flight recorder in addition to a radio down link. The many features of SPREE will require data storage in excess of a gigabyte (1000 megabytes). This large amount of information can not be transmitted with the limited bandwidth generally provided. Therefore, non-critical information will be available only from the flight recorder.

Power constraints prohibit the use of several low capacity recorders. Instead, Amptek is adapting new high density recording media, thus requiring only one or two recording devices. Media include helical scan tape recorders (similar to VHS video rec orders) and optical 'Write Once, Read Many' (WORM) disks.

## II. Background

### A. Optical Disks

One of the newest media technologies is the polyester optical disk, better known as 'laser disk'. Current models can write to the disk once by burning digital 'spots', then read back the data nearly an infinite number of times. The data is not prone to magnetic erasure and has an archive life exceeding ten years. Future designs will be able to write and erase data several times by means of localized thermal reflow of the optic media.

Mountain Optotech Incorporated manufactures a ruggedized 200 megabyte optical disk drive for $6749. Survivability specifications for this unit include vibration tolerance of 13g rms between 20 and 2000 Hz, and shock to 30g for 11 msec. An extended performance version intended for spacecraft applications expands the vibration specification to 22g rms over the same frequencies and a has temperature range of -55 to 90 degrees Celsius.

Despite its rugged specifications, the 200 megabyte capacity does not make the Mountain Optotech drive a first choice for a flight recorder.

### B. Exabyte Cartridge Tape Subsystem (CTS)

Exabyte has combined an 8mm Sony camcorder mechanism with proprietary Application Specific Integrated Circuits (ASICs). The result is a 2 gigabyte tape drive that fits in a standard full height PC drive slot and consumes less than 20 watts of power. Data is transferred via a Small Computer Systems Interface (SCSI) port at a sustained rate of 1.8 megabits per second.

Storage density is determined by the techniques used in reading and writing to the tape. The size of a data bit's magnetic

signature on the tape can not be smaller than the air gap in the read head. Earlier data recorders using the nine track technique pull the tape past stationary heads. The maximum data rate can be determined by the number of finite magnetic transitions that can occur in an inch of tape multiplied by the tape speed in inches per second (ips). With helical scanning, the head assembly spins diagonally over a moving tape, creating an illusion to the head of a much faster tape speed. This process produces a micro stepping of adjacent helical tracks, yielding a very high density and allowing the tape to move slower.
Price of commercial units is $3,500.

## III. Development

Amptek's goal is to produce a high capacity flight recorder suitable for scientific experiments aboard shuttle. There are numerous applications for a 2 gigabyte recorder so initial efforts have concentrated on adapting the helical scanning technology. The following development cycle is based on the Exabyte CTS.

### A. Environmental Specifications

#### 1. Vibration

Mounting the tape drive requires some knowledge of the shuttle's vibration environment. Vibration and induced loads will vary depending on instrument's mounting location. The shuttle was designed to carry this type of instrument on a palette. The mounting rail in the bottom of the shuttle bay allows slip movement in the z axis. Palettes can therefore flex with a natural frequency ranging from 8 to 14 Hz. To prevent scientific experiments from increasing the gain of a palette, the natural frequency of an experiment must be no less than 35 Hz.

The following table illustrates that the most severe induced loads will be felt in the z direction.

Table 1. Enveloped Accelerations (g)

| | | | |
|---|---|---|---|
| Lift Off | x-axis | y-axis | z-axis |
| | +5.80 | +1.55 | +13.15 |
| | -9.00 | -1.55 | -12.28 |
| Landing | x-axis | y-axis | z-axis |
| | +7.47 | +2.98 | +8.19 |
| | -7.70 | -3.03 | -5.12 |

The most concerning element in table 1 is the magnitude of the +13.15g data point in the z-axis. The temporal component will be obtained to determine how much of this acceleration can be attenuated by isolators.

The sine surveys in figure CTS-1 were performed at AFGL and point out several construction points that can be improved.

x-axis: This curve is the most difficult to identify. Removal of the door and tape carriage should decrease gain. Fortunately, the resonant frequency is well above the projected natural frequency of the vibration mount and will be far into isolation by this point.

y-axis: The lowest of the resonant frequencies is observed in the pendulum like swing of the case and carriage. Stiffening by replacing the hanging bracket with a horizontal strut is planned.

z-axis: The vertical axis has the most complex response. The first peak is due to overhang by the top cover. The second peak is the carriage and eject mechanism. Small responses are believed to be other tape transport mechanisms and the backplane. Substitution of the carriage and elimination of the eject feature will be the first modification.

Analysis of a first try vibration isolation can be found in figute CTS-2. This configuration consists of off the shelf parts and has not yet been optimized for a 35 Hz natural frequency. The isolators are mounted at four points located radially from the equipment center of gravity. This eliminates second order peaks in gain at higher frequencies. Isolator materials include a high damping (C/Cc=0.15) rubber.

Figure CTS-3 depicts a ruggedized enclosure / vibration mount for the tape subsystem.

2. Atmosphere

A peculiarity with magnetic tape is that it requires humidity. If the tape is allowed to dry out, the ferrous oxide 'flakes' off its Mylar backing. Loss of recording media can be prevented by enclosing the recorder inside a hermetic box with a controlled amount of moisture. This enclosure is also required because of outgasing that may be present from the recorder's components. (This commercial recorder has not been assembled from vacuum compatible parts). The flight recorder will therefore consist of two boxes, a vibration mounted box within a hermetic enclosure.

B. Electrical Specifications

The tape drive (or any other type of drive) will communicate to the DPU via a Bridge Controller Board (BCB). The BCB will be mounted next to the tape drive within the hermetic box and together will be considered a flight recorder. The BCB will translate the SCSI bus into an efficient serial format for use by the DPU.

Adding a BCB isolates the quirky housekeeping overhead of specific drives from the DPU. This black box approach unburdens the DPU and enhances the reliability of the primary objective, detection of shuttle charging. Other benefits include reduced EMI & EMC through the use of coaxial cable, and easier swapping between drive technologies that use a SCSI bus.

CTS Sine Survey

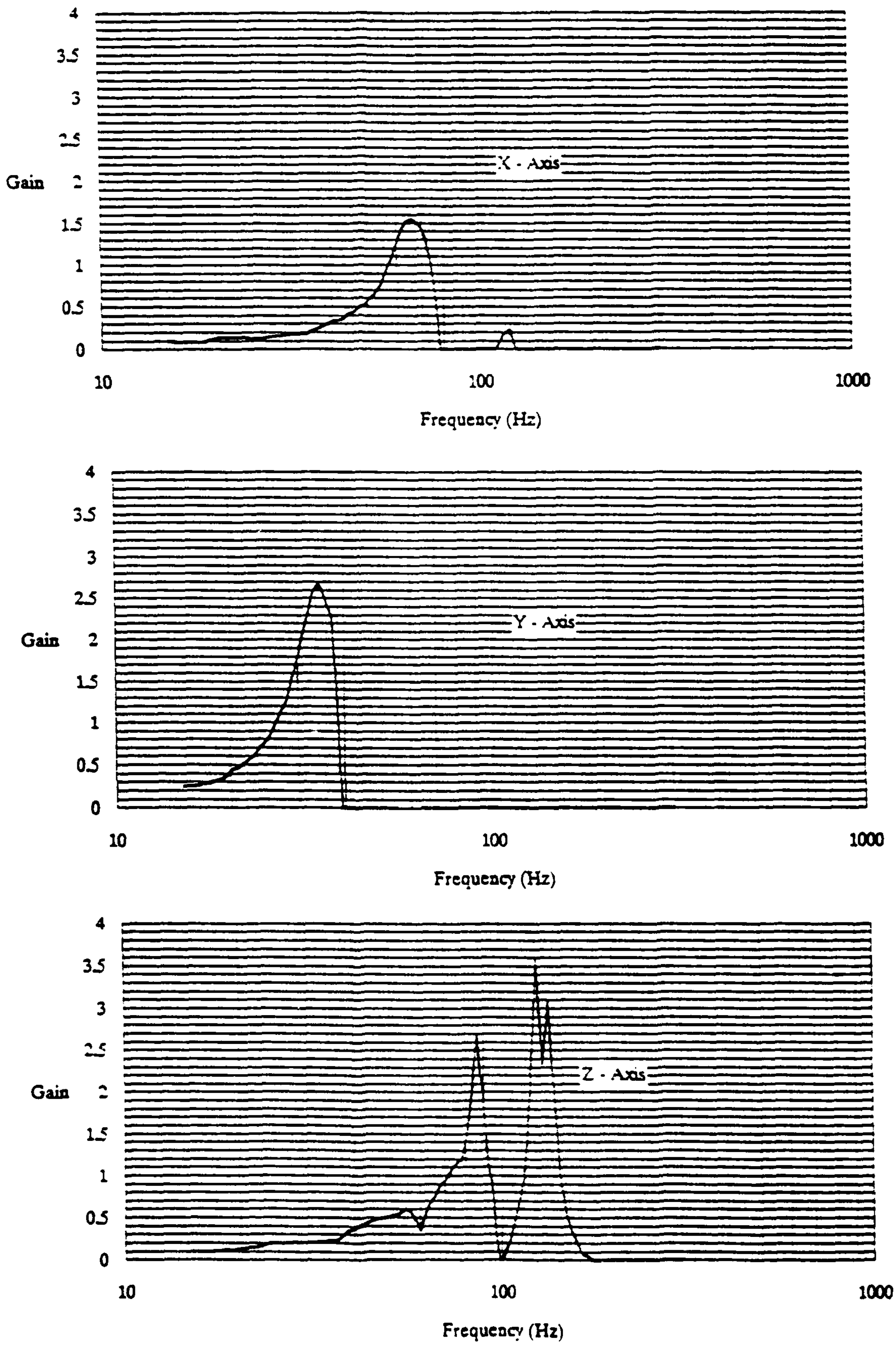



FIGURE QR3-13

Isolator Transfer Function

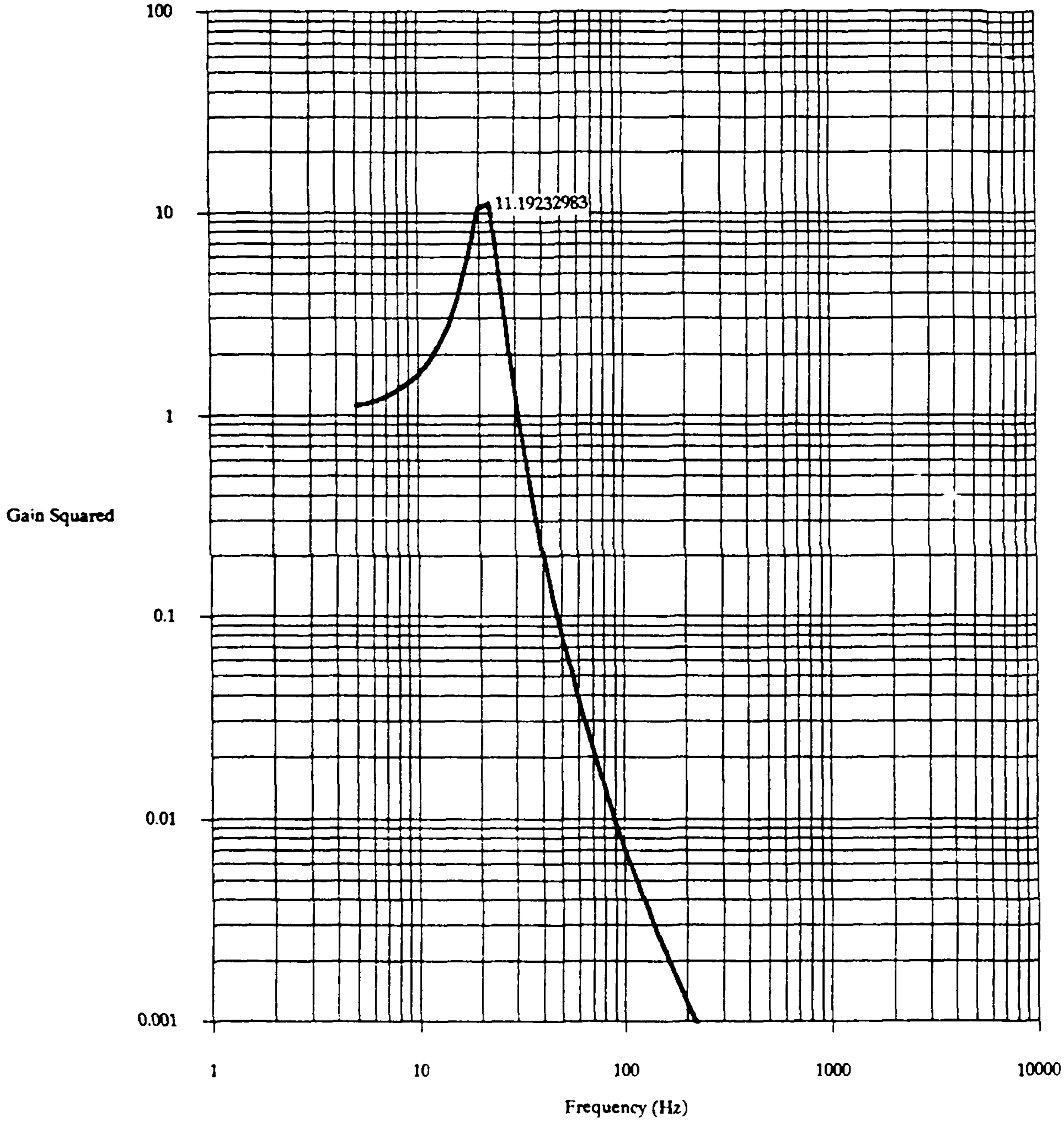



FIGURE QR3-14

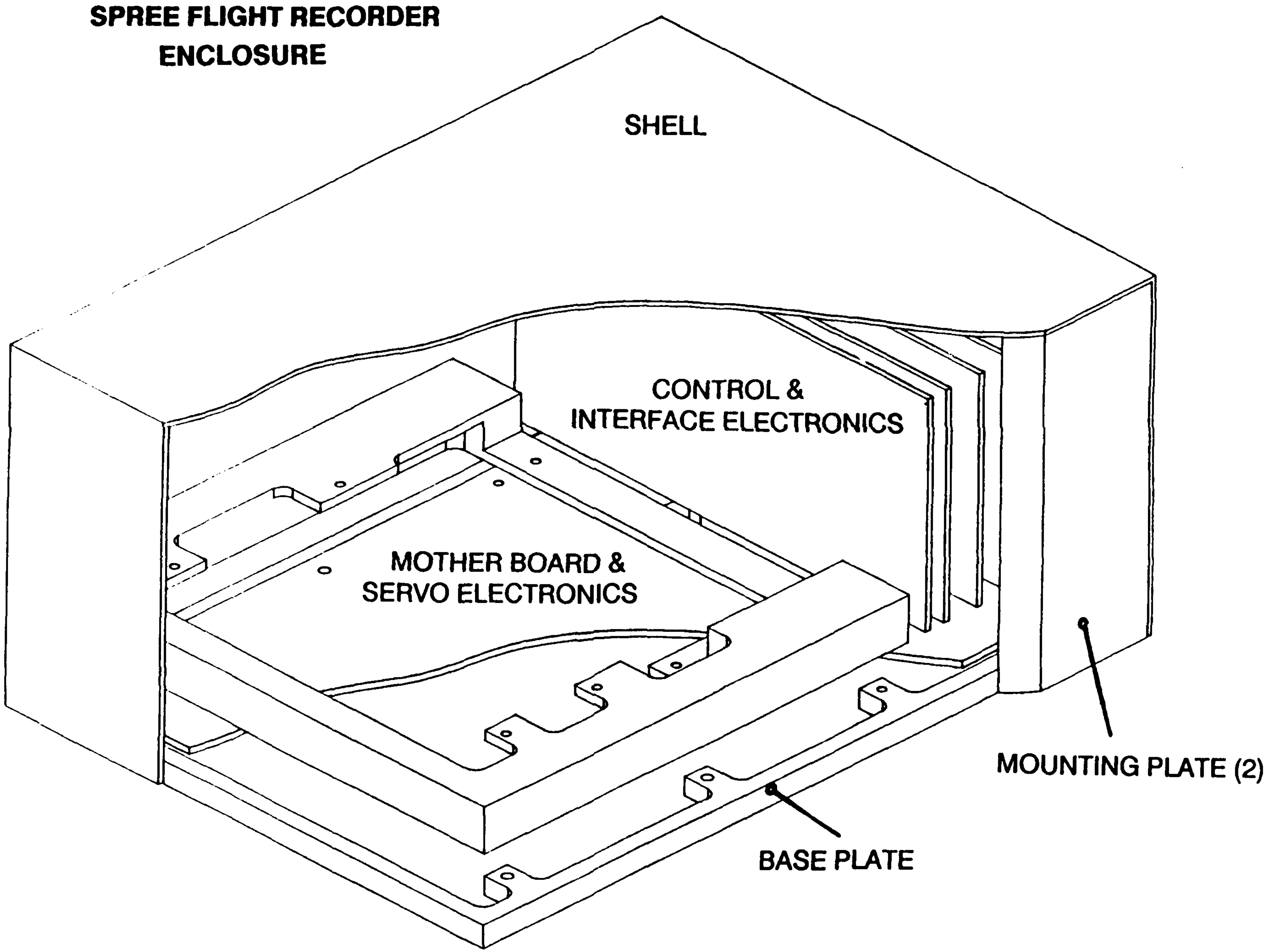


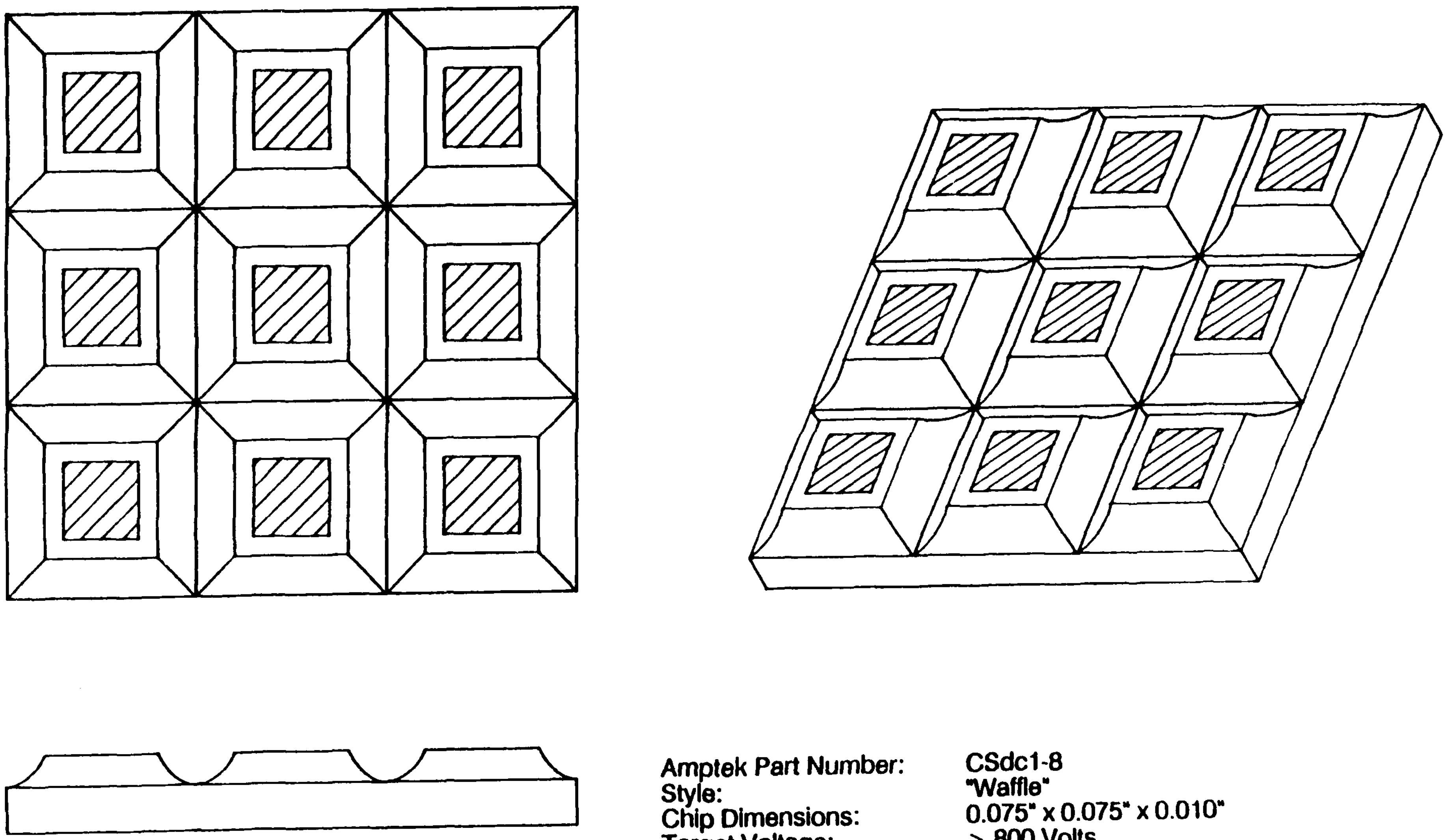

FIGURE QR3-15

## HIGH VOLTAGE OPTOCOUPLER

The first custom high voltage diodes were received from the manufacturer, CSdc, in May. These diodes were designed with small bonding pads. The small pad was to allow IR light to penetrate the silicon chip and generate hole-electron pairs. The diodes did not perform as expected due to the highly doped epitaxial layer on the diode. Silicon is normally transparent to IR light, however, heavy doping in the p-layer made the silicon opaque.

Our next attempt will etch back the epitaxial p-layer to expose more of the diode's depletion region. This region between the p- and n-layers is where photoconductivity takes place. A sample drawing of the new configuration appears in figure HV-1.

Fiber optic faceplates have been used succesfully as a light transmitting medium. Dielectric tests are planned to demonstate the optocoupler's isolation capabilities.



| | |
|---|---|
| Amptek Part Number: | CSdc1-8 |
| Style: | "Waffle" |
| Chip Dimensions: | 0.075" x 0.075" x 0.010" |
| Target Voltage: | > 800 Volts |
| Target Current: | < $20 \times 10^{-9}$ Amps |

Active area inceased 240%.

FIGURE QR3-16

## ROTARY DRIVE

In order to increase angular coverage of the 270 degree analyzer, it will be rotated around an appropriate axis. Since for shuttle missions there is no spacecraft spin to perform this function, a mechanical system must be developed to rotate the sensors. Oscillatory motion is preferable to continuous rotation because it eliminates the need for a rotary interface and the angular coverage may be adjusted. However, oscillatory motion makes much greater demands on the motor since it requires periodic reversal of direction of rotation.

A major constraint on the design of the drive system is the requirement that magnetic fields generated by the drive motor do not significantly alter electron trajectories inside the analyzers. Both the choice and location of the motor are important in this respect.

Several approaches to this problem have been investigated. The first was to procure an integral stepper motor, speed reducer, and rotary platform which would both support and drive an analyzer. Such a device is sold by Schaeffer Magnetics, who call it a "rotary actuator." The speed reducer utilized is an especially compact type known as an Harmonic Drive. From discussions with Schaeffer, it was clear that this approach was workable and relatively straightforward. However, the cost of this approach was a strong deterrent and warranted investigation of alternatives.

Another approach considered is to use a rotary table mounted on a large diameter ball bearing and driven by Kapton belts and pulleys from a motor/speed reducer. This would have the advantage that the drive would be hollow, ie, a large hole would exist along the drive axis through which the cabling could be routed, minimizing cable length and deflection. Another advantage is that the motor could be moved as far away from the sensors as necessary in order to eliminate magnetic interference. Sprocketless Kapton belt technology is well proven for Shuttle use and has the useful characteristics of vibration isolation and zero backlash.

In searching for appropriate speed reducers, we discovered that compact Harmonic Drive reducers are available from their manufacturer, Harmonic Drive in Wakefield, Ma., at a small fraction of the cost of the Schaeffer units. One of their products is made to be close-coupled with a motor, and has a planar mounting surface at its output, on which the sensor may be mounted. This motor - reducer combination is equivalent to the Schaeffer unit, with the added flexibility that the motor can be chosen for magnetic characteristics and can be mounted further away from the sensor if necessary. This system is reasonable in cost and relatively simple to implement and is the one we have chosen to develop and test a prototype drive.

Consideration was given to the need for a closed loop control system using an optical encoder for absolute position feedback to the motor controller. This would minimize the possibility of positioning errors due to accumulated step errors. The decision was made to build and test the prototype as an open loop system with optical position reference points at the ends of the scan range. This approach is simpler and the optical encoder may be added later if it proves necessary.

2 - D Codes: A Personal Computer version of the 2-D codes HEMIV and HEMIY were developed to give us simulation capabilities independent of the mainframe computers at AFGL. This was done using the Microsoft Fortran77 V3.20 compiler with mixed success. The HEMIV code (using elliptical trajectories with no fringe fields) converted easily and produced identical results on 286 and 386 level PC's with or without a math coprocessor. HEMIY (with entrance aperture fringe fields and trajectory tracing) did not do so well. All its graphics and listing capabilities had to be stripped out and the grid size it could deal with minimized. It was then divided into two separate programs, the first half to get the field solution and the second to do the geometric factor integration. The development was done on a 286 class PC-AT with no math coprocessor and both halves ran and produced correct results. However, attempts to run it on a PC with a math co-processor were unsuccessful. It was tested on a 286 level PC and on a 386 level PC each with a 80287 math coprocessor and it bombed in both cases. The symptoms were different on the two machines but a reasonable guess would be that the problem is with the Microsoft interface to the coprocessor trig routines. A decision was made to table the project until a better Fortran compiler can be acquired.

3 - D Codes: The 3-D development on CLPH3D continues. At this time we have produced a field solution and generated a set of test trajectories and traced them through the 3-D grid. A comparison between the central plane potentials and those from the equivalent HEMIY potential solution was made. This comparison was excellent and confirmed that the assumptions made for the 2-D code fringe fields were correct. We are now evaluating the trajectories. We still have not implemented the interface between the 3-D grid and the 2-D elliptical code through the interior of the instrument. Also, graphics must be added, and the geometric factor integration code added. The grid will then be expanded in the third dimension and the CLPH3D's simulation capabilities explored.

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12, Briarcroft Road
Woodingdean
Brighton, BN2 6LL
U.K.

In this quarter year considerable time has been spent looking at the problem of applying particle correlators to high resolution spectrometers of the type that might fly on future Shuttle missions.

One of the greatest problems is found to be that of processing several (~10) fast pulse streams simultaneously without having massive duplication of electronics. This is particularly relevant to the high frequency (Mega-Hertz) Buncher mode (electrons only). In this mode the time between particle arrivals is measured by hardware in units of a 20 MHz clock in each of the ten channels separately. It is not possible to perform this measurement via software using CPU interrupts since the response to interrupts is of the order of a microsecond, even for the fastest processors.

The hardware is required to measure the time between pulse arrivals by counting the 20MHz clock and to present those measurements to the CPU. This initiates a software increment of the appropriate memory location to generate a histogram of the number of events as a function of time separations (64), angle zones (10), and energy levels (32). It is assumed that these histograms are read out via telemetry faster than the spectrometers are rotated. (So there is no need to bin on-board as a function of rotation angle).

Each pulse stream requires one six/seven bit counter, a six bit latch, a J-K flip flop, two monostables, and four Nand gates. The J-K is used to catch overflow (measurements >64 units of 50nS) and in those cases inhibit the incrementing of the histogram. With this number of gates per pulse stream it becomes possible to consider Gate arrays. In the first instance it was thought best that all of the Buncher electronics for the 10 streams could fit onto one Gate Array. However as the response of the CPU in making the histogram incrementation can be slow, ten separate gate array units might be configured, each to include the hardware for one stream, 64 X 8 bits of memory, and the necessary incrementation logic. Then the CPU could read out the full Histogram from each unit, say once per energy level. In this way the detection effeciency (% of time accepting pulses for measurement) is maximised. Further work on this aspect are awaiting discussions in june with Amptek who have more experience with gate array design.

of a few tens of mS (or say the energy step dwell time) into four equal time bins corresponding to wave phases 0-90, 90-180, 180-270, & 270-360 degrees. If there is no significant modulation then the variation of these four sums should be of the order of that expected by Poisson statistics. (i.e. differences of the order of the square root of the average total). It is a simple calculation to find the difference between the greatest and the smallest and divide that by the square root of the average. This gives a direct measure of the significance of any modulation present in the particles at the beam modulation frequency. Data can be very compressed with the CPU only transmitting significant data ( > 3 sigma). Furthermore the CPU can use the knowledge of where in velocity space the modulation significance is highest to concentrate the resolving power to that region.

## WORK PLAN

The scheduled research falls into a number of specific topics listed here:

1) An early design step is to choose the number of resolution bins in frequency, energy, zone angle, and rotation angle for each of the two particle species. For a given data rate this naturally implies a tradeoff between these measured parameter resolutions against temporal resolution. It also sets the required memory size for holding these average ACFs.

2) Study CPU types available and choose an appropriate processor. At this time the transputer looks like being a likely choice. In the near future an auroral rocket will use a group of 4 transputers to replace 36 microcomputers. The transputer has the advantage of true parallel processing and can be arranged in fault- tolerant configurations.

3) Verify that the chosen CPU type can provide the processing required via a software simulation. In the case of transputers this simulation will determine the number of transputers required.

4) Design the hardware block components. Particular problem areas are: a) Fast pulse timing for the Buncher mode on ten data streams, (b) Fast memory accessing by transputers, (c) Effective division of the modulation reference signal into four equal time bins.

5) Liase with AMPTEK over the specific hardware design with a view to AMPTEK constructing the particle correlator cards.

6) Liase with AMPTEK over the flight software. It is expected that the software will be a joint production.

7) Design a checkout system that can effectively test the required flight functions.

8) Support AMPTEK in constructing, testing, checkout, launch preparations, in flight monitoring, and subsequent post flight data interpretation.

==================================================

## EXPECTED FREQUENCIES & TECHNIQUES

As stated above the type of particle correlation method depends on the expected frequencies of modulation:

### (a) Natural 1-10 MHz modulations

Electrons (only) are expected to undergo interactions with waves at these high frequencies: the local upper hybrid frequency, Fuh (1-7 MHz) and local electron gryofrequency, Fg (1.4MHz- orbit location dependant) and its low harmonics. Bernstein or Electron Cyclotron Harmonic Waves are to be expected at (n + 1/2) Fg and at Fuh.

At these high modulation frequencies, approximately ten times higher than the highest expected count rates, the one bit 'buncher' mode is the ideal method of correlation. This method involves measuring the time of arrival between successive electrons in units of say a 20MHz clock. A histogram of the number of measured separations as a function of separation units (50nS) is accumulated over periods typically of 10S or more depending on the average count rate. This method is directly equivalent to averaging many one bit correlation functions, each with only two bits set. It is much easier to produce in hardware and there is neglible loss in detection efficiency since the probability of obtaining more than two bits set in say a one bit correlator data take of 64 samples at 20MHz is neglible for typical count rates of a few times 100,000 per second.

This technique has been used successfully to identify modulations at mega- Hertz frequencies present on the natural auroral beams above auroral arcs.

### (b)Natural 0-10KHz modulations

This lower frequency range contains both the lower hybrid frequency (1-10KHz) and the ion gyrofrequencies ( < 1KHz). Naturally occurring modulations at these frequencies are expected both in ions and electrons.

Average Auto-Correlation Functions (ACFs) can be generated in software from say groups of 128 sample takes at 20KHz. On AMPTE UKS this technique was further simplified by converting each set of samples first to one bit by comparing each sample with the average of that set. One bit ACFs were rapidly calculated and averaged. At kilo-Hetrz frequencies a NSC800 processor can achieve >90% detection efficiencies (% of time taking samples). The disadvantage of this technique is that it is only sensitive to the strongest modulation present. With the higher computing powers now available (e.g. transputers) full multi-bit ACFs should be possible. There are also dedicated ACF chips but microprocessor based designs offer greater flexibility given the range of instrument modes and frequency- energy- 2-D angular binning needed for the results.

### (c) Artificial Beam Modulation

As mentioned above the active electron and ion beams might be deliberately modulated at kilo-Hertz frequencies. If the frequency and phase of this reference signal is present on board then the spectrometer detected particle samples can be directly cross correlated to look for this modulation. In principle a cross correlator could be achieved as in (b) above but a specialised technique has many advantages.

If the reference signals can be generated at four times the modulation frequency by PLL then counts can be summed up over periods

When particles are in velocity resonance with waves, either particle energy is transferred to the waves resulting in wave amplitude growth and particle decceleration, or wave energy is transferred to the particles resulting in particle acceleration and wave damping. In either case particles in velocity resonance will become phase bunched with the wave. This is observable as fluxes of particles at the resonant velocity (or appropriate energy level) being modulated in time at the wave frequency. Measurements of these particle modulations as a function of frequency, energy level, and particle direction of motion, allow us to identify directly by experiment those regions of particle velocity space contributing to wave growth and wave damping.

Active beam experiments with beams actively modulated at kilo-Hetrz frequencies allow for the beam electrons or ions to be tagged or to stimulate natural emissions at these frequencies. Any beam electrons returning to the Shuttle bay should also be modulated at this frequency and identified directly by a particle correlator. Furthermore any beam electrons which have undergone acceleration or decceleration, or natural electrons which have interacted with them via wave- particle interactions, will also be modulated at the beam modulation frequency and identified as such.

There are several methods which can be employed by which particle modulations can be measured. The choice of method depending mainly on the frequency range of interest and to a lesser extent on other information available on-board at the particle correlators (i.e mission specific). For a realistic design a specific particle spectrometer is assumed here.

## EXAMPLE APPLICATION

For initial hardware design purposes it is assumed that there are two pre-existing particle instruments, each a combined electron and ion spectrometer. It is further assumed that these instruments are of the 270 degree type of electrostatic analyser with each instrument having a field of view 100 x 10 degrees ( in the form of ten detection zones each of 10 x 10 degrees spread around in a fan). It is also expected that these two instruments are mounted in such a way that thay can be rotated about an axis perpendicular to the plane of these fan field of views. A resulting total field of view is achieved approaching the maximum 2pi available to a Shuttle bay mounted instrument (i.e. subject to limits imposed by shaddowing from other instruments in the bay).

Active electron and ion beam experiments usually allow for the frequency modulation of the beam at kilo-Hertz frequencies. It is assumed in this design study that a signal corresponding in frequency and phase to this beam modulation frequency is available on-board for use as a reference signal by the particle correlator.

As there are two identical particle instruments (each electrons and ions) it is planned to have identical correlator units in each one. Thus the inputs available to each of these correlator units are 20 pulse streams ( 2 species x 10 zones ), one beam modulation reference signal, and some instantaneous monitor of the spectrometer energy level.

PRDA-QR4

# PROTOTYPE INSTRUMENTATION AND DESIGN STUDIES

AMPTEK, INC.
6 De Angelo Drive
Bedford, MA 01730

September 21, 1988

R&D status Report No. 4
June 5, 1988 through September 4, 1988

Contract #F19628-87-C-0094

## SENSOR DESIGN

Hemispheres necessary for the building of a nested tri-quadraspheric electrostatic analyzer ($Q^3ESA$) were ordered and received this quarter. These hemispheres were manufactured to our specified outer and inner diameters from type 6061-T6 aluminum. The hemispheres have been stress relieved as part of their fabrication. They are specified to be within ±.001 inch inner diameter and +.000/-.005 of their outer diameter. Their wall thickness is .050.

This is material acceptable for spaceflight hardware. The stress relief and tolerances are necessary to insure that the machined and mounted quadraspheres are mutually concentric. A high degree of concentricity minimizes fringe fields that may distort an $Q^3ESA$'s responses.

A vacuum chamber thermal control shroud was installed and tested in the vacuum chamber. At first the shroud performed properly, but after several cold/heat cycles it developed a leak. This leak must be located and repaired before the system is used to test any contamination sensitive instruments such as the $Q^3ESA$. The thermal vacuum chamber testing is necessary to verify new designs to insure they can survive a space environment.

A visit was made to Martin Marietta in Denver Colorado to discuss mechanical, electrical, and thermal interface problems typical to a space shuttle flown payload. Martin is an integration contractor for several shuttle payloads and has extensive experience in developing design criteria for successful shuttle experiments. Specifics of the environment, including vibration levels, operating thermal ranges, typical electrical interfaces, and mandatory safety requirements were covered. Development of a prototype space qualified $Q^3ESA$ requires not just meeting scientific performance criteria, but in also meeting environmental specifications of spaceflight.

Amongst many useful subjects covered in the Denver meeting was the possible use of a "cold plate" to provide thermal control to shuttle bay experiments. This device attaches to a controlled temperature fluid circulating system in the shuttle which regulates the temperature of the cold plate to a +2°C to +50°C temperature range. Assuming the use of such a device simplifies the development and design of the sensor hardware since it greatly reduces the possible thermal extremes that an instrument may see in spaceflight.

The surface area of a "cold plate" is limited. The mounting feet of the tape recorder were reoriented to accommodate mounting to the smaller surface area. (See the attached drawing.)

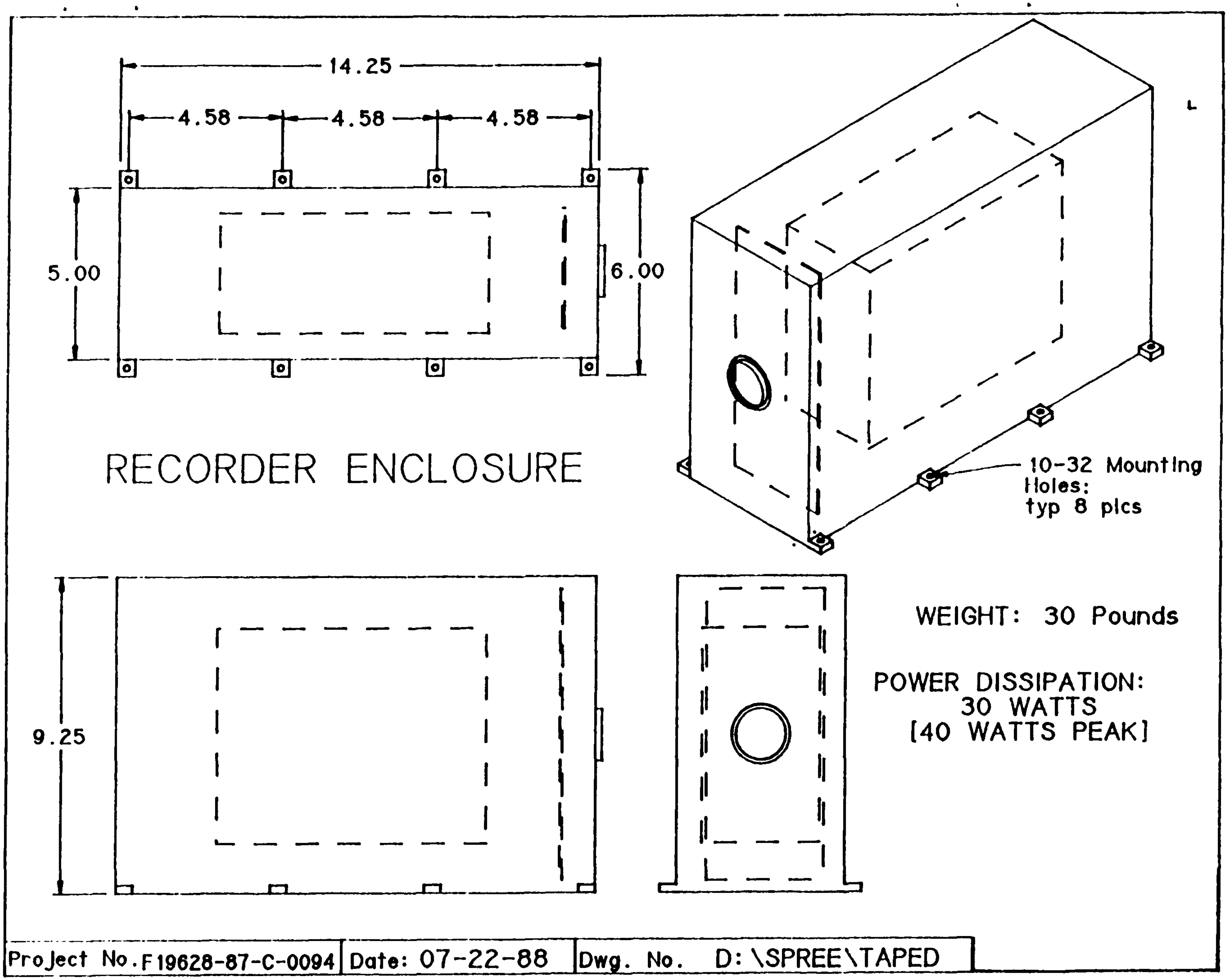

14.25
4.58
4.58
4.58
5.00
6.00
RECORDER ENCLOSURE
10-32 Mounting Holes: typ 8 plcs
9.25
WEIGHT: 30 Pounds
POWER DISSIPATION:
30 WATTS
[40 WATTS PEAK]
Project No. F19628-87-C-0094
Date: 07-22-88
Dwg. No. D:\SPREE\TAPED

FIGURE QR4-1

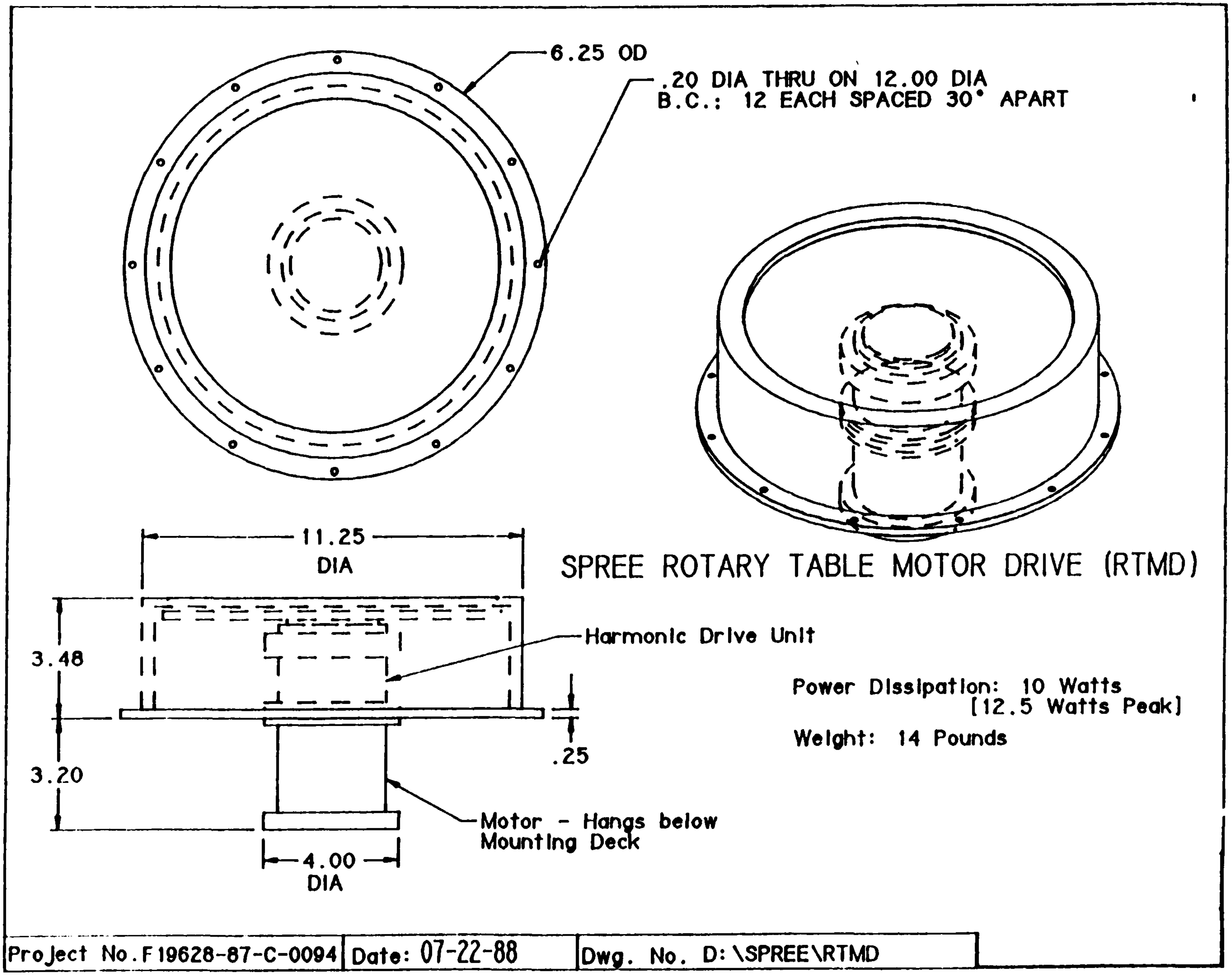

6.25 OD
.20 DIA THRU ON 12.00 DIA
B.C.: 12 EACH SPACED 30° APART
11.25
DIA
SPREE ROTARY TABLE MOTOR DRIVE (RTMD)
Harmonic Drive Unit
3.48
Power Dissipation: 10 Watts
[12.5 Watts Peak]
Weight: 14 Pounds
.25
3.20
Motor - Hangs below
Mounting Deck
4.00
DIA
Project No. F19628-87-C-0094
Date: 07-22-88
Dwg. No. D:\SPREE\RTMD

FIGURE QR4-2

## DATA PROCESSING UNIT FOR 270 DEGREE NESTED SENSORS

The parts selection and design for the CPU boards is now complete. A prototype CPU board was constructed to verify the proper operation of the memory chips and several other circuits. The PC board layout is now underway and the first PC boards should be available for testing during the next quarter.

The following parts are being used for the CPU board:

| Part # | Description |
|---|---|
| 80C86-2 | 8 MHz CMOS microprocessor |
| 82C84A | Clock generator |
| 82C59A | Interrupt controller |
| 82C54 | Timer/counter |
| HM-65642 | 8k x 8 static RAM |
| HM-6617B | 2k x 8 CMOS PROM |
| EP320 | Altera EPLD |
| 74AHCT373 | 8-bit latch |
| 74HC245 | 8-bit transceiver |
| 74FCT244 | 8-bit buffer |
| IDT7130/7140 | Master/slave dual-port RAM |

A preliminary PC board layout was performed for the D400 accumulator board to verify that the proposed board size of 9.75" x 6.25" is appropriate. It is, and the final D400 board layout will be completed during the next quarter.

Included is a partial block diagram of SPACE (Spacecraft Particle Correlator Experiment). Only half of SPACE is shown in the block diagram, the other half being identical. The operation of the various modules has been described in previous quarterly reports.

Not shown in the block diagram is the control CPU. SPACE will be controlled by an 80C86 with a full complement of support chips. Communications between SPREE and SPACE will be performed through a pair of dual-port RAMs.

The microcontroller modules for SPACE will consist of an 80C31 microcontroller, an HM6516 static RAM and an 87C64 EPROM. Not shown on the block diagram is a redundant microcontroller module, which will automatically switch on-line in case one of the primary microcontroller modules fails.

The high-frequency buncher modules will contain an Altera EP1800 EPLD, an HM6516 and other support logic. This module has been prototyped with discrete components and is now being fit into programmable logic devices to reduce board space requirements.

## SPREE FLIGHT RECORDER

Amptek has decided to use helical scanning tape technology for the flight recorder. A vendor, Exabyte of Boulder CO, has been chosen to supply commercial grade hardware. Amptek will repackage the drive for space flight.

Two members from Amptek visited Exabyte in August to discuss the recorder's intended application. After talking to several of the recorder's designers, we are confident that this is a worthy device. Information was also obtained for methods to enhance the drive's reliability.

The flight recorder, currently designated FR20, will store over one billion bytes of data during the SPREE mission. For redundancy, two recorders will be flown side-by-side.

Present work involves the design of a hermetic box for the drive mechanism. Magnetic tapes requires humidity to retain their magnetic coating so the enclosure will contain a controlled environment. The planned Bridge Controller, BC, will modify the internal air temperature of the box before the tape mechanism is initialized.

Signet Tool & Engineering has been contacted to manufacture the enclosure. We are planning to machine the base from a single block of aluminum. The cover will also be made from a single sheet. All external bolts will be captured.

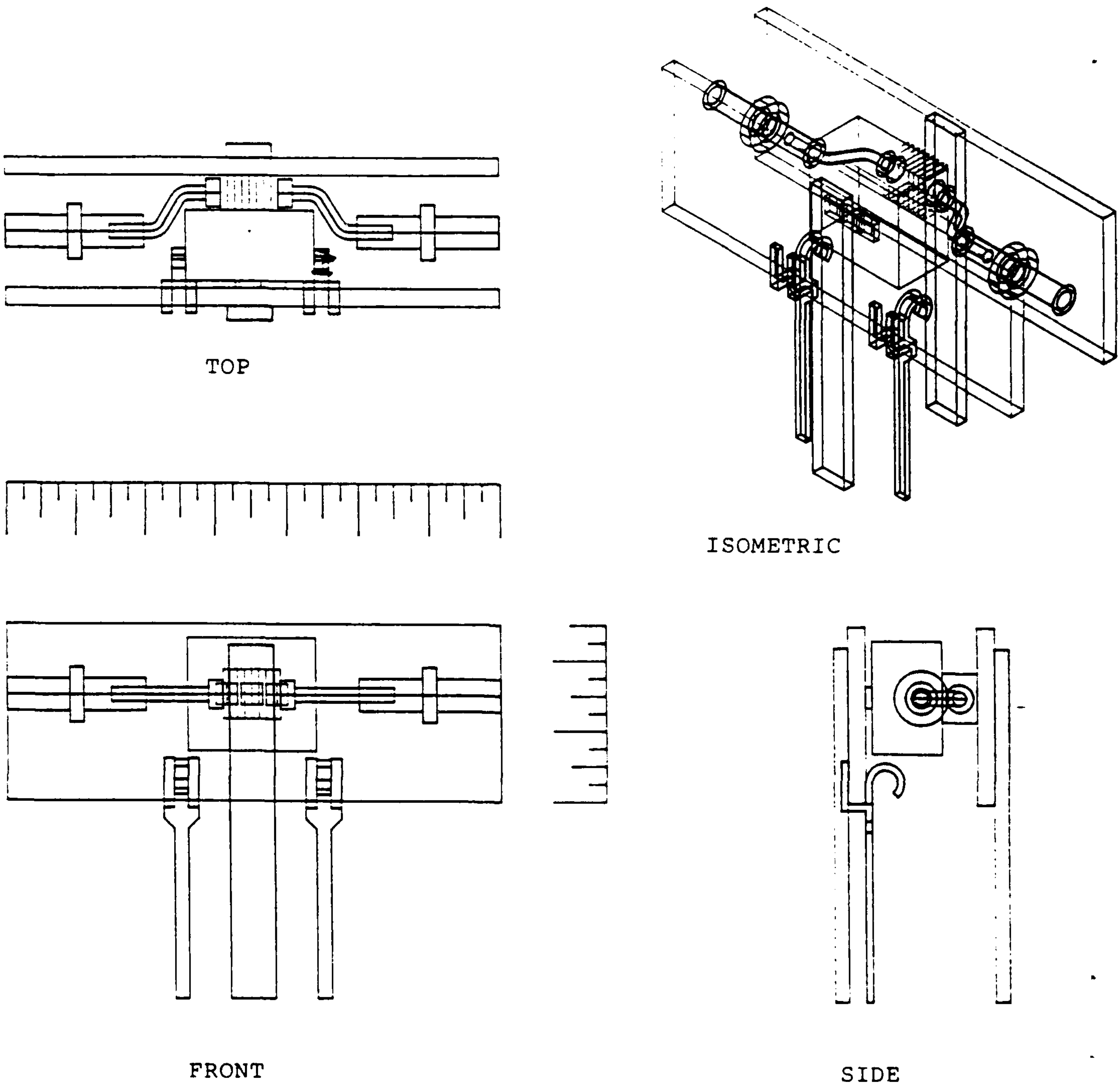
# HIGH VOLTAGE OPTOCOUPLER

The high voltage photodiode has evolved a new design. The previous approach with single junctions has been abandoned. A more compact and efficient diode stack is now being considered. Delivery of sample parts is expected at the end of September.

A May plant trip to CSdc in New Jersey helped advance the optocoupler's design. Observation of manufacturing techniques and capabilities suggested that a stacked junction diode would be a much better component.

A wire frame model of the proposed optocoupler follows. Two prominent features are the high voltage outlets and the method for heat removal. For high voltage, hollow pins are cast into the optocoupler's epoxy body. Their location is chosen for highest isolation. Connections can be soldered to the pins. Heat removal is accomplished by two tin plated copper bars on either side of the body. The bars are soldered to heat sinks on a printed circuit board. Leads for the LEDs are also soldered to the p.c. board.

The first prototype will have a blocking voltage of 12kV and couple 80uA of output current for 20mA of input current. The unit will measure 0.700" x 0.250" x 0.200"




Scale = 5:1

HIGH VOLTAGE OPTOCOUPLER

**FIGURE QR4-3**

SPACECRAFT PARTICLE CORRELATOR EXPERIMENT

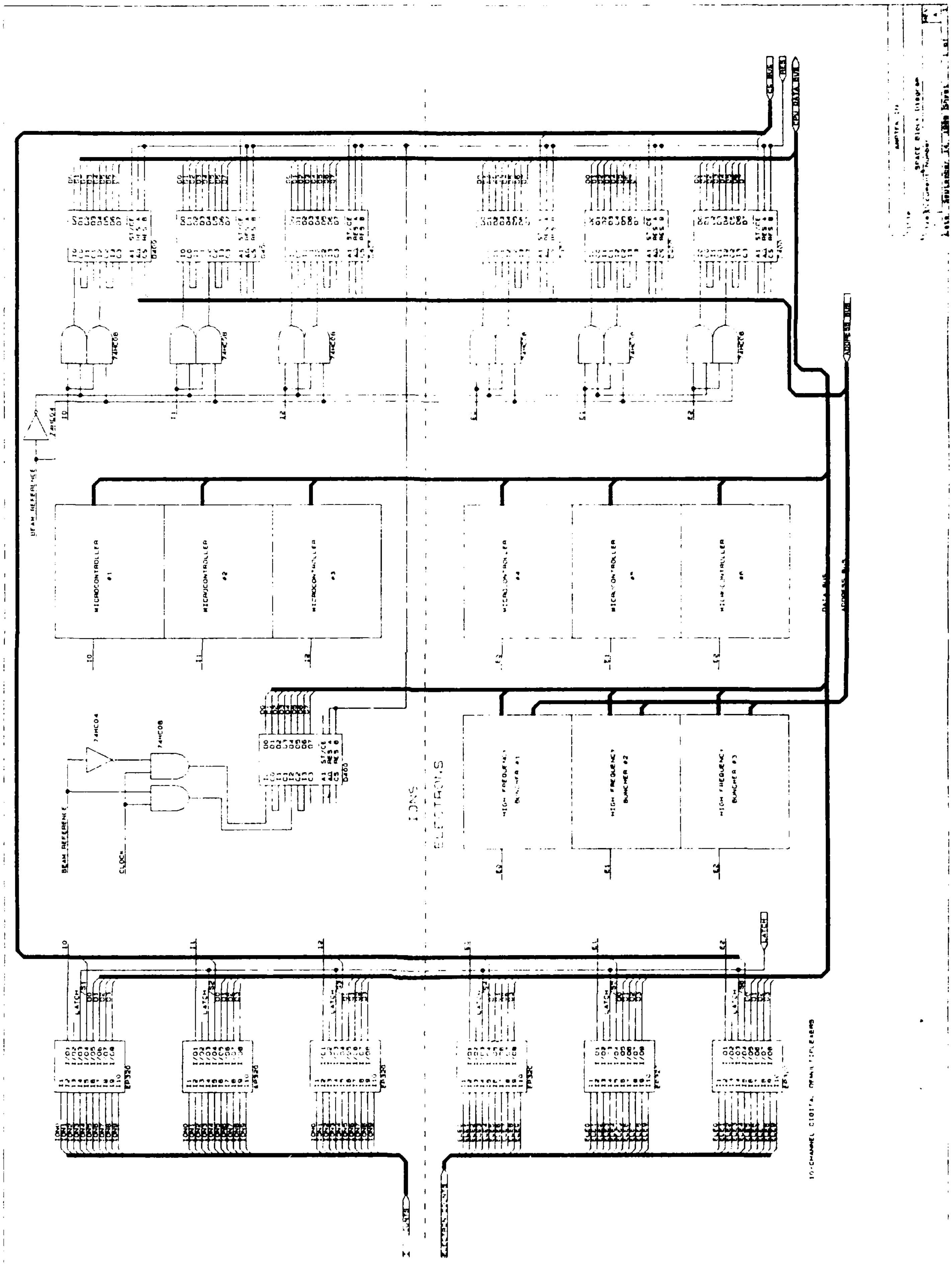
Work of consultant: Dr. Paul Gough, Brighton, UK

An early design step has been to choose the number of resolution bins in frequency, energy, zone angle, and rotation angle for each of the two particle species. This sets the required memory size for holding these average ACFs and the telemetry requirement. At the same time Electron Gun Pulse patterns have been specified. In particular H.F. buncher and pulse patterns have been designed to enable an "Electron Radar" mode of operation.

Considerable time was spent studying CPU types available with eventual choice of $\mu$PAK607C31 as an appropriate processor that combines processing power with large memory (PROM + RAM) in one 40 pin DIL.

Over this quarter the main task has been to design the hardware of the fast pulse timing for the Buncher mode. I have constructed and fully tested a buncher breadboard unit formed out of 74HC parts that is fully microprocessor bus compatible. This design is now being studied by AMPTEK with a view to reducing a large part of the circuit onto a gate array chip. A selectable clock will be included to give a variety of frequency ranges, equivalent to distance ranges in the "Electron Radar" mode.

This work is part of the overall liaison with AMPTEK over the complete hardware design with a view to AMPTEK constructing the particle correlator cards.. The software of the chosen microprocessor type is now being studied with a view to the software writing being a joint effort with AMPTEK.


IONS
ELECTRONS
MICROCONTROLLER #1
MICROCONTROLLER #2
HIGH FREQUENCY BUNCHER #1
HIGH FREQUENCY BUNCHER #2
HIGH FREQUENCY BUNCHER #3
74HC04
74HC08
BEAM REFERENCE
CLOCK
LATCH
DATA BUS
ADDRESS BUS
CPU DATA BUS

## INSTRUMENT SIMULATION PROJECT

An advanced Fortran compiler for Personal Computers was purchased to run the HEMIV and HEMIY 2-D simulation codes. This compiler had to be fully main frame compatible to accommodate the developed and proven simulation codes. A Ryan-McFarland Fortran was selected. This product has been implemented and HEMIV and HEMIY codes are now executing on our PC. Attached are listings of the current state of these two programs.

Instructions for building a input data file for HEMIY were written. This allows a designer to model and test a design using the HEMIY code without involving a programmer to execute the program. The development of this sort of in-house "user friendly" code was a major objective of our simulation development program. A copy of these instructions is enclosed.

3-D code development on CLPH3D has continued. This code still requires a main frame processor. Output results between it and the PC run HEMIY are being made and to an extent they are being used to cross prove each other. The fringe field solutions of CLPH3D are very accurate and can be used to test 2-D approximations used on HEMIY. On the other hand, the trajectory analysis done by HEMIY is being used to confirm the output of the more computational rigorous CLPH3D. The interface between the 3-D grid and 2-D elliptical code has been started. A graphics display and output is being developed to help interpret and understand the results.

## HEMIY DATA FILE DOCUMENTATION

The first step in using the simulation code developed by AMPTEK is to construct a data file defining a 2-D grid, the instrument walls, a set of apertures, and the location of all relevant fixed voltages. The data file used by HEMIY specifies the above information in an abbreviated format. In order to define it, first consider Figure 1. Figure 1. illustrates a 12 x 8 grid which is of adequate size to illustrate all the relevant features modelled by HEMIY. The two plates of the instrument, labeled RI and RO are shown in dark black, the four apertures, labeled A1 through A4 are shown in red, and the remaining fixed voltage line segments, F1 through F6 are shown in blue.

The data file corresponding to Crude Instrument consists of fifteen lines of information as shown in Table 1. below:

```
 C1:  DATA FILE FOR CRUDE INSTRUMENT.  AUGUST 1988
 C2:    12     8     2     8
 C3:4,4,4,5    6,6,3,6   10,10,3,6   12,12,3,6
 C4:6    1,2.0    2,5.5       3,6.0  6,8.0  7,8.5  8,11.0
 C5:3   1,90.0  6,90.0   12,-180.0
 C6:3   1,-5.0    6,0.0       12,0.0
 C7:3   1,-5.0    6,0.0       12,0.0
 C8: 150.0    6,12,3,3   4
 C9:-137.0    6,12,6,6   5
C10:    0.0   4,12,7,7   6
C11:    0.0    4,4,1,4   6
C12:    0.0    4,4,5,7   6
C13:    0.0  12,12,1,3   6
C14:    0.0  12,12,6,7   6
C15: -98.0     7,7,3,6   9
```

TABLE 1.

Card labels 'Cn:' have been added for reference and are not part of the real data file. C1 is an 80 column header card; C2 gives the four values NX, NY, NL, AND NV; C3 gives the four apertures; C4 defines the vector quantity 'R'; C5 defines 'ALP'; C6 defines 'XB', and C8 through C15 specify fixed voltage line segments.

HEMIY constructs an NX x NY distorted rectangular grid with NL logical levels Each grid point has (x,y) coordinates based on the three vector quantities R, ALP, and XB. Note the shorthand used in C4, C5 and C6. For example the R vector is specified by six number pairs each consisting of an index and an R coordinate. HEMIY calculates R(4) and R(5) by linear interpolation. Similarly, only three pairs are needed to define ALP with ALP(1) through ALP(6) having the value 90.0 and ALP(7) through ALP(11) containing values at 45 deg. intervals from 45.0 through -135.0. XB varies linearly from -5.0 at XB(1) to 0.0 at XB(6) and is zero for XB(7) through XB(12). The grid coordinate algorithm should be fairly obvious by now. HEMIY treats R as a Y-coord and XB as a X-coord whenever ALP is 90.0. It treats R and ALP as a polar grid whenever ALP is not 90.0.

You may have noted that nothing has been said about C7 and about what NL does. That is because at this time they do nothing but must be included in the data file for historical reasons. When the data file structure was originally designed, I had in mind modelling the box containing the instrument. This would have required a non=polar region between RO and the box. Since this was just a cosmetic enhancement, it was never implemented. Note that the value of NL is ignored, but that C7 must be identical to C6.

C3 defines the four apertures shown in Figure 1. Each aperture is defined by a set of four integers, IX1,IX2,JY1,JY2. Hence the aperture is the line segment connecting points (IX1,JY1) and (IX2,JY2). A1 is the input aperture, and HEMIY uses the A1 coordinates to define the injection plane and the size of the aperture, A2 defines RI and RO, A3 is the 180 degree aperture which is no longer used and A4 is the exit aperture which is also ignored at this time.

The remaining cards are the voltage cards. There are NV of them and the first two are the inner and outer plate voltages. The format is simple: a voltage value, four integers specifying a line segment using the C3 notation and an integer flag. They were intended to be order independent since the flag is sufficient to define them, but that is not guaranteed. The flag values for the plates must be 4 and 5 and the other fixed voltages should be flagged with a 6. C15 gives the interface plane between the trajectory code region and the region where the elliptical trajectory is applied and it must be flagged with a 9. Note that the voltages specified on C8, C9, and C15 are replaced with appropriate values by HEMIY. The ground voltages on C10 through C14 are used as supplied and hence should be zero.

One final note on the data file format. C1 is an ASCII label and is read with a Fortran (A80) format. C2 must be (4I5) since there are some other diagnostic parameters read from C2 that should all default to zero. The remaining card images are read as Fortran free form, meaning that their values may be separated by commas, one or more spaces, or a carraige return, but that there must be the correct number of values.

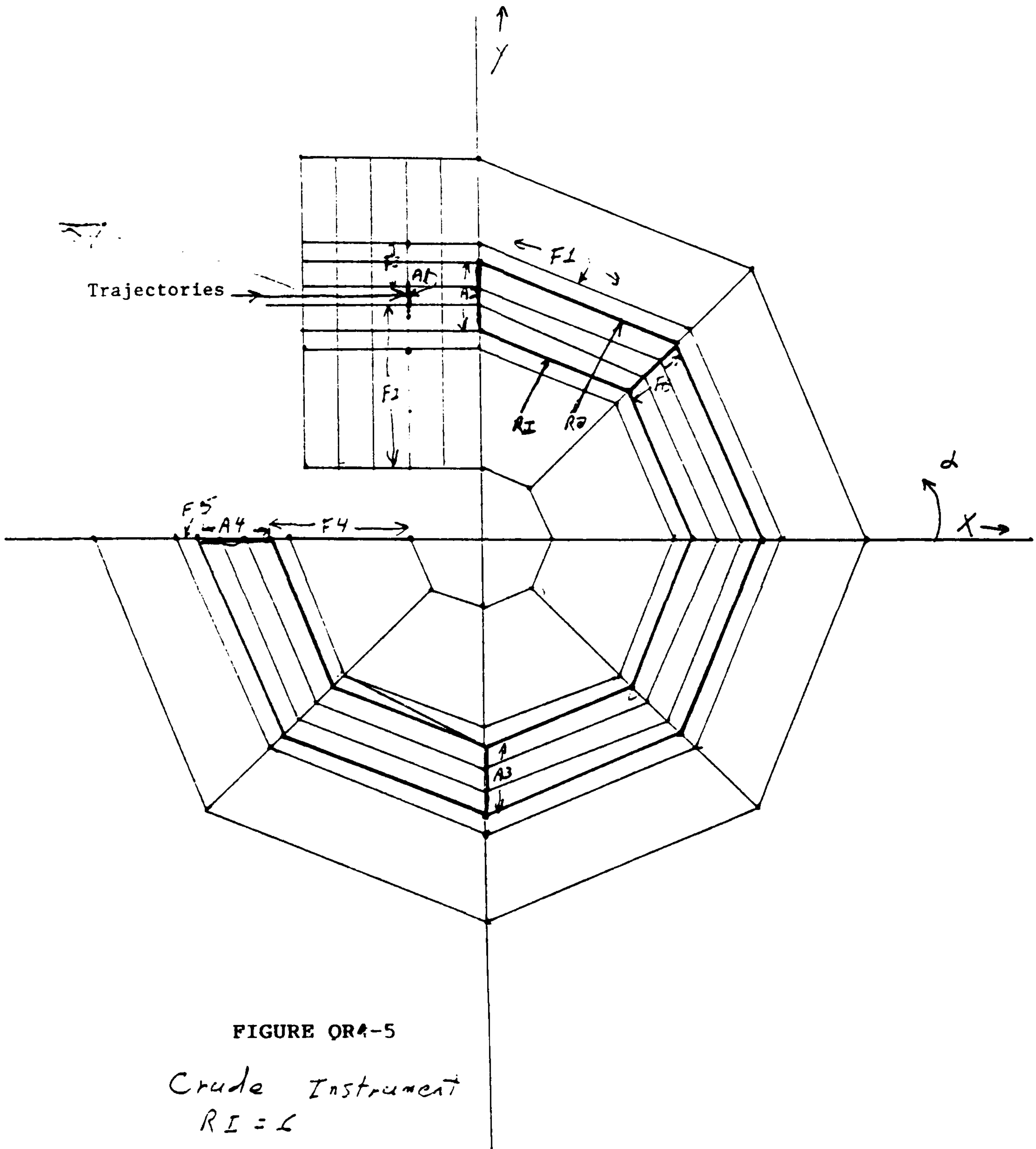



FIGURE QR4-5

Crude Instrument
RI = 6
Ro = 8

```
      PROGRAM HEMIY
      IMPLICIT REAL*8 (A-H,O-Z)
      CHARACTER TEST(101,101),ICHAR(10),LTMP(7)*14
      DIMENSION ITOT(101,101),NSUM(21),ISUM(101),JSUM(101),
     -RHOD(15),LSUM(101),MSUM(101),NEOT(21),NACT(21)
      DIMENSION XX(756),YY(756),MCON(7,1394),VV(756),MBDY(2,130),
     -ANEL(1394),SK(44,756),CHD(1394),VP(137),PP(756),RR(756),IAP(16),
     -IN(4),FCON(26),AINV(3,5),TAU(1394),IBK(4),WW(17,18)
      COMMON /ORB/ XDOT,YDOT,XP,YP,NTSAV,TIMIN,NOWEL,NOWSD
      COMMON /INST/ RIP,ROP,RIA,ROA,ENOT,EK
      DATA ISUM,JSUM,LSUM,MSUM /404*0/
      DATA ICHAR/' ','2','3','4','5','6','7','8','9','9'/
      DATA TAU /1394*0./
      DATA TEST /10201*' '/
      DATA NEOT,NAOT /42*0/
      DO 10 I=1,41
        DO 10 J=1,41
          ITOT(I,J)=0
 10   CONTINUE
      DO 20 N=1,21
        NSUM(N)=0
 20   CONTINUE
      NTRJ=0
      PI=ACOS(-1.)
      RAD=PI/180.
      THETA=90.
      THETA=THETA*RAD
      ST=SIN(THETA)
      M180=0
C     MTHD=0
      REWIND7
      REWIND4
      REWIND8
      REWIND11
C
C  SET QUADRATURE LIMITS
       ME=41
       MP=41
       MR=11
       MA=11
C      CALL SSWTCH(6,ISW6)
       ISW6=1
       IFPLT=1
       IF(ISW6.EQ.1) THEN
         PRINT*,'M180,ME,MP,MR,MA = ',M180,ME,MP,MR,MA,'  ENTER NEW VALUE
     +S'
         READ(5,*) M180,ME,MP,MR,MA
         PRINT*,'M180,ME,MP,MR,MA = ',M180,ME,MP,MR,MA
         IFPLT=2
         IF(M180.GT.3) THEN
           M180=M180-4
C          MTHD=1
         ENDIF
       ENDIF
C
C  DEFINE GEOMETRY
       ENOT=1000.
       CALL GEOMB(VOUT,VINN,RIP,ROP,RIA,ROA,ENOT,NX,NY,NBDY,XX,YY,VV,CHD,
     +VP,MBDY,PP,RR,IAP,AEND,IPRT,IBK,NBK)
       NTOT=NX*NY
```

```
      NEL=(NX-1)*(NY-1)*2
C
C  DEFINITION OF PLATE AND APERTURE RADII
      RB=(RIP+ROP)/2
      DRP=ROP-RIP
      DIA=RCA-RIA
      RA=DIA/2.
      EAL=DIA
C
C  SET 180 DEG APERTURE PARAMETERS
      IF(M180.EQ.1) THEN
C  SLIT OF CONSTANT DELTA R
        RC=EAL/2.
        WRITE(6,'(10X,''APERTURE AT 180 IS SLIT.  WIDTH ='',F8.3,'' CM''
     -  )') EAL
      ELSE IF(M180.EQ.2) THEN
C  CIRCLE OF RADIUS RC
        RC=RA
        WRITE(6,'(A1,6X,''APERTURE AT 180 IS CIRCLE.  RADIUS ='',F8.3,
     +''  CM'')') ' ',RC
      ELSE
C  DEFAULT IS NO APERTURE
        M180=0
        RC=(ROP-RIP)/2.
        WRITE(6,'(5X,''NO APERTURE AT 180 DEGREES'')')
      ENDIF
C
C  DEFINITION OF U QUADRATURE PARAMETERS
      UIP=RB/RIP
      UOP=RB/ROP
      UIA=RB/RIA
      UOA=RB/ROA
      UINC=(UIA-UOA)/MR
      UST=UOA+UINC/2
      IF(MR.LE.1) THEN
        MR=1
        UST=1.
      ENDIF
C
C  DEFINITIONS OF ALPHA QUADRATURE PARAMETERS
        ALFB1=-ASIN(RA/RB)
        ALFB2=-ALFB1
        ALFINC=(ALFB2-ALFB1)/MA
        ALFAST=ALFB1+ALFINC/2
        IF(MA.LE.1) THEN
          MA=1
          ALFAST=0.
        ENDIF
C
C  DEFINITION OF EK QUADRATURE PARAMETERS
      EK1=0.85
      EK2=1.15
      EKINC=(EK2-EK1)/ME
      EKST=EK1+EKINC/2
      DE=(VINN-VOUT)/21000.
      EB=1.-10.*DE
      IF(ME.LE.1) THEN
        ME=1
        EK1=1.
        EK2=1.
```

```
         EKINC=1.
         EKST=1.
      ENDIF
C
C  DEFINITION OF PHI QUADRATURE PARAMETERS
      PHI1=-9.0/ST
      PHI2=15.0/ST
      PHI1=PHI1*RAD
      PHI2=PHI2*RAD
      PHINC=(PHI2-PHI1)/MP
      PHIST=PHI1+PHINC/2
      IF(MP.LE.1) THEN
        MP=1
        PHI1=0.
        PHI2=0
        PHINC=1./ST
        PHIST=0.
      ENDIF
      ASUM=0
      RIA=RB-RC
      ROA=RB+RC
      UIA=RB/RIA
      UOA=RB/ROA
C
C  DEFINE CONNECTIVITY
      CALL CNEC(NX,NY,NEL,NBDY,NBDW,MCON,MBDY,ANEL,XX,YY,VV,VP)
C  SOLVE FOR POTENTIALS
      DEBYE=0.
      CALL CLP2D(DEBYE,SK,VV,CHD,VP,NTOT,NBDW,NEL,NBDY,MBDY,XX,YY,MCON,
     +ANEL,ENOT)
C     READ(11) NXX,NYY,((WW(I,J),I=1,NXX),J=1,NYY)
C     IF(MTHD.EQ.1) THEN
C       KK=0
C       DO 130 JJ=1,NY
C         DO 130 II=1,NX
C           KK=KK+1
C           IF(NX.LE.NXX) THEN
C             WW(II,JJ)=WW(II,JJ)-VV(KK)
C             VV(KK)=WW(II,JJ)
C           ELSE
C             WW(II,JJ)=VV(KK)
C           ENDIF
C130    CONTINUE
C     ENDIF
C
C  DO CONTOURS
      NLB=12
      FCON(1)=VOUT
      FCON(2)=-1.
      FCON(3)=1.
      FCON(4)=VINN
      IN(1)=1
      IN(2)=6
      IN(3)=7
      IN(4)=12
      CALL VEXP(4,IN,FCON)
      IFPLT=0
C
C  DO QUADRATURES
      IX=IAP(1)
```

```
      MMR=(MR-1)/2+1
      MMA=(MA-1)/2+1
      MAT=1
      IF(M180.NE.2) THEN
        MAT=MA
        MMA=1
        MA=1
      ENDIF
      MB=MAX(MA,MAT)
      DO 30 L=1,MR
        U=UST+(L-1)*UINC
        R=RB/U
        DO 90 JJ=IAP(3),IAP(4)
          NN=2*(NX-1)*(JJ-1)+2*(IX-1)+1
          CALL ACRDS(0.D0,XX(IX),R,NN,XX,YY,VV,MCON,AINV,AREA,ACHK)
          IF(ABS(ACHK-1.).LT.1.D-6) GO TO 110
 90     CONTINUE
 110    CONTINUE
        IF(MR.EQ.1) UINC=U*U/RB
        IF(MB.LE.1) ALFINC=U/RB
C
C  DEFINITIONS OF ALPHA QUADRATURE PARAMETERS
        DR=ABS(RB-R)
        CALF=(R*R+RB*RB-RA*RA)/2./RB/R
        ALFA1=-ACOS(MIN(1.,CALF))
        ALFA2=-ALFA1
C
        DO 30 MM=1,MA
          IF(M180.EQ.2) THEN
            ALFA=ALFAST+(MM-1)*ALFINC
            IF(ALFA.LT.ALFA1.OR.ALFA.GT.ALFA2) GO TO 30
            SQ=SQRT(RC*RC-(RB*SIN(ALFA))**2)
            RCAL=RB*COS(ALFA)
            RIA=RCAL-SQ
            ROA=RCAL+SQ
            UIA=RB/RIA
            UOA=RB/ROA
          ENDIF
C
          DO 40 I=1,ME
            EK=(EKST+(I-1)*EKINC)*ENOT
            DO 40 J=1,MP
              PHI=PHIST+(J-1)*PHINC
              XP=XX(IAP(1))
              YP=R
              NOWEL=NN
              NOWSD=2
              CALL ACRDS(0.D0,XP,YP,NOWEL,XX,YY,VV,MCON,AINV,AREA,ACHK)
              SPEED=SQRT(EK+AINV(3,5))
              XDOT=SPEED*COS(PHI)
              YDOT=SPEED*SIN(PHI)
              NTRJ=NTRJ+1
              CALL TRAJ(AINV,0.D0,XSTEP,XSGN,YSGN,VV,XX,YY,IPRT,NTRJ,NEL
     +        ,MCON,ITEST,LOC,TAU,IFPLT,RB,AEND,EEND,BET,REND)
              DO 60 M=1,MAT
                IF(M180.NE.2) THEN
                  ALFA=ALFAST+(M-1)*ALFINC
                ENDIF
                IF(MR.EQ.1.AND.MB.EQ.1) THEN
                  I1=I
```

```
              I2=J
            ELSE IF(ME.NE.1) THEN
              I1=I
              IF(MP.NE.1) THEN
                I2=J
              ELSE IF(MR.NE.1) THEN
                I2=L
              ELSE
                I2=MAX(M,MM)
              ENDIF
            ELSE IF(MP.NE.1) THEN
              I2=J
              IF(MR.NE.1) THEN
                I1=L
              ELSE
                I1=MAX(M,MM)
              ENDIF
            ELSE
              I1=L
              I2=MAX(M,MM)
              MMR=MR
            ENDIF
            TEST(I1,I2)='Q'
            IF(M180.NE.2.AND.(ALFA.LT.ALFA1.OR.ALFA.GT.ALFA2)) GO TO
     +      60
            TEST(I1,I2)=ICHAR(ITEST)
            IF(ITEST.NE.1) GO TO 60
            ISUM(I)=ISUM(I)+1
            JSUM(J)=JSUM(J)+1
            LSUM(L)=LSUM(L)+1
            MSUM(M)=MSUM(M)+1
            ASUM=ASUM+1./U/U/U
            ITOT(I,J)=ITOT(I,J)+1
            NRHO=(REND-RIP)/(ROP-RIP)*21.+1.
            NRHO=MIN(MAX(1,NRHO),21)
            NSUM(NRHO)=NSUM(NRHO)+1
            NEO=(EEND-1000.-VOUT)/(VINN-VOUT)*21.+1.
            NEO=MIN(MAX(1,NEO),21)
            NAO=(BET+8.)/16.*21.+1.
            NAO=MIN(MAX(1,NAO),21)
            NEOT(NEO)=NEOT(NEO)+1
            NAOT(NAO)=NAOT(NAO)+1
60        CONTINUE
40      CONTINUE
        IF(L.EQ.MMR.AND.MM.EQ.MMA) THEN
          IF(I1.GT.1.AND.I2.GT.1) THEN
            DO 120 JJ=1,MIN(41,I2)
              WRITE(6,'(1X,41A3)') (TEST(I,JJ),I=1,MIN(41,I1))
120         CONTINUE
          ENDIF
        ENDIF
30    CONTINUE
      IF(I1.GT.1.AND.I2.GT.1) THEN
        WRITE(6,33) PHI1/RAD
33      FORMAT(//' PHI START=',F5.1,1X,'DEGREES')
        DO 80 II=1,MIN(41,MP)
          WRITE(6,'(1X,41I3)') (ITOT(I,II),I=1,MIN(41,ME))
80      CONTINUE
        WRITE(6,34) PHI2/RAD
34      FORMAT(1X,'PHI END=',F4.1,1X,'DEGREES')
```

```
      WRITE(6,35) EK1,EK2
35    FORMAT(1X,'ENERGY START=',F7.5,35X,'ENERGY END=',F7.5)
     ENDIF
     WRITE(6,100)
100  FORMAT(//8X,'EBEG',12X,'PHI',14X,'R',12X,'ALP',11X,'EEND',11X,
    -'BEND',12X,'RHO')
     DO 24 I=1,MAX(MR,MB,ME,MP,21)
       LTMP(1)=' '
       LTMP(2)=' '
       LTMP(3)=' '
       LTMP(4)=' '
       LTMP(5)=' '
       LTMP(6)=' '
       LTMP(7)=' '
       EK=EKST+(I-1)*EKINC
       PHI=PHIST+(I-1)*PHINC
       DPHI=PHI/RAD
       U=UST+(I-1)*UINC
       R=1./U
       ALFA=ALFAST+(I-1)*ALFINC
       EO=EB+FLOAT(I-1)*DE
       BO=-8.+(FLOAT(I)-.5)*16./21.
       RO=RIP+(FLOAT(I)-.5)*(ROP-RIP)/21.
       ISS=ISUM(I)+JSUM(I)+LSUM(I)+MSUM(I)
       IF(I.LE.21) ISS=ISS+NEOT(I)+NAOT(I)+NSUM(I)
       IF(ISS.LE.0) GO TO 24
       IF(I.LE.ME) WRITE(LTMP(1),4001) ISUM(I),EK
       IF(I.LE.MP) WRITE(LTMP(2),4001) JSUM(I),DPHI
       IF(I.LE.MR) WRITE(LTMP(3),4001) LSUM(I),R
       IF(I.LE.MB) WRITE(LTMP(4),4001) MSUM(I),ALFA/RAD
       IF(I.LE.21) WRITE(LTMP(5),4001) NEOT(I),EO
       IF(I.LE.21) WRITE(LTMP(6),4001) NAOT(I),BO
       IF(I.LE.21) WRITE(LTMP(7),4001) NSUM(I),RO
4001   FORMAT(I4,F10.5)
       WRITE(6,6) LTMP
24   CONTINUE
6    FORMAT(7(1X,A14))
C    WRITE(6,101)
     IISM=0
     DO 23 I=1,I1
       IISM=IISM+ISUM(I)
23   CONTINUE
     GF=(ASUM)*RB*RB*ST*ST*PHINC*UINC*EKINC*ALFINC
     THETA=THETA/RAD
     WRITE(6,102)
102  FORMAT(1X/1X/1X,'***THETA**SUM OVER ALL GEOMETRIC FACTOR')
     WRITE(6,9)THETA,IISM,GF
9    FORMAT(1X,F10.5,I10,1PE15.5)
     IF(ME.GT.2) THEN
       CALL FWHM(ME,ISUM,EKST,EKINC,EBAR,SIGE,ERAN,MAXX)
       ERAN2=FLOAT(IISM)*EKINC/FLOAT(MAXX)
2001   FORMAT(//1X,'EBAR,SIGE,  DELTA E OVER E  = ',4F10.5)
       WRITE(6,2001) EBAR,SIGE,ERAN/MAX(EBAR,1.D-6),ERAN2
     ENDIF
     IF(MP.GT.2) THEN
       CALL FWHM(MP,JSUM,PHIST,PHINC,PBAR,SIGP,PRAN,MAXX)
       PRAN2=FLOAT(IISM)*PHINC/FLOAT(MAXX)/RAD
       WRITE(6,2002) PBAR/RAD,SIGP/RAD,PRAN/RAD,PRAN2
2002   FORMAT(//1X,'PBAR,SIGP,PFWHM               = ',4F10.5)
     ENDIF
```

```
      IF(MR.GT.2) THEN
        CALL FWHM(MR,LSUM,UST,UINC,UBAR,SIGR,URAN,MAXX)
        URAN2=FLOAT(IISM)*UINC/FLOAT(MAXX)
        WRITE(6,2003) 1./UBAR,SIGR,URAN,URAN2
2003    FORMAT(//1X,'RBAR,SIGR,RFWHM                 = ',4F10.5)
      ENDIF
      IF(MB.GT.2) THEN
        CALL FWHM(MB,MSUM,ALFAST,ALFINC,ABAR,SIGA,ARAN,MAXX)
        ARAN2=FLOAT(IISM)*ALFINC/FLOAT(MAXX)/RAD
        WRITE(6,2004) ABAR/RAD,SIGA/RAD,ARAN/RAD,ARAN2
2004    FORMAT(//1X,'ABAR,SIGA,AFWHM                 = ',4F10.5)
      ENDIF
      DE=.12/21.
      EB=.94+DE/2.
      CALL FWHM(21,NEOT,EB,DE,EOBR,SIGE,EORAN,MAXX)
      WRITE(6,2005) EOBR,SIGE,EORAN
2005  FORMAT(//1X,'EOBR,SIGE,EFWHM                 = ',3F10.5)
      DB=16./21.
      BB=-8.+DB/2.
      CALL FWHM(21,NACT,BB,DB,BOBR,SIGB,BORAN,MAXX)
      WRITE(6,2006) BOBR,SIGB,BORAN
2006  FORMAT(//1X,'BOBR,SIGB,BFWHM                 = ',3F10.5)
      DR=(ROP-RIP)/21.
      RHOB=RIP+DR/2.
      CALL FWHM(21,NSUM,RHOB,DR,ROBR,SIGR,RORAN,MAXX)
      WRITE(6,2007) ROBR,SIGR,RORAN
2007  FORMAT(//1X,'ROBR,SIGR,RFWHM                 = ',3F10.5)
      END
      SUBROUTINE CNEC(NX,NY,NEL,NBDY,NBDW,MCON,MBDY,ANEL,XX,YY,VV,VP)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION MCON(7,*),ANEL(*),XX(*),YY(*),VV(*),AINV(3,5),MBDY(2,*),
     +VP(*)
C
      NEL=0
      NBDW=NX+2
      NTOT=NX*NY
      N1=NTOT-NX
      IMID=(NX-1)/2+1
      DO 10 NN=1,N1
        IN=MOD(NN-1,NX)+1
        IF(IN.EQ.NX) GO TO 10
        NEL=NEL+2
        MCON(1,NEL-1)=NN
        MCON(3,NEL-1)=NN+NX
        IF(IN.LT.IMID) THEN
          MCON(2,NEL-1)=NN+1+NX
          MCON(1,NEL)=NN
          MCON(2,NEL)=NN+1
          MCON(3,NEL)=NN+1+NX
        ELSE
          MCON(2,NEL-1)=NN+1
          MCON(1,NEL)=NN+1
          MCON(2,NEL)=NN+1+NX
          MCON(3,NEL)=NN+NX
        ENDIF
 10   CONTINUE
C
      DO 20 II=4,7
        DO 20 JJ=1,NEL
          MCON(II,JJ)=-1
```

```
 20     CONTINUE
C
       DO 70 II=1,NEL
         DO 70 JJ=1,3
           IF(MCON(JJ+3,II).GT.0) GO TO 70
           DO 60 KK=1,NEL
             IF(KK.EQ.II) GO TO 60
             DO 50 LL=1,3
               IF(MCON(LL,KK).EQ.MCON(JJ,II)) THEN
C
C  POINT     LL,KK = JJ,II
                 DO 40 MM=1,3
                   IF(MM.EQ.JJ) GO TO 40
                   DO 30 NN=1,3
                     IF(NN.EQ.LL) GO TO 30
                     IF(MCON(NN,KK).EQ.MCON(MM,II)) THEN
C
C  NN,KK = MM,II    HENCE KK AND II ARE ADJACENT TRIANGLES WITH
C      SIDE LL-NN OF KK == SIDE JJ-MM OF II
                       I1=MIN(JJ,MM)
                       I2=MAX(JJ,MM)
                       K1=MIN(LL,NN)
                       K2=MAX(LL,NN)
                       IS=3-I1
                       IF(IS.EQ.I2) IS=3
                       KS=3-K1
                       IF(KS.EQ.K2) KS=3
                       MCON(IS+3,II)=KK
                       MCON(KS+3,KK)=II
                     ENDIF
 30                CONTINUE
 40              CONTINUE
               ENDIF
 50          CONTINUE
 60        CONTINUE
 70    CONTINUE
C
       DO 80 II=1,NEL
         DO 80 JJ=4,6
           IF(MCON(JJ,II).GT.0) GO TO 80
           I1=1
           I2=3
           IF(JJ.EQ.4) I1=2
           IF(JJ.EQ.6) I2=2
           J1=MOD(MCON(I1,II)-1,NX)+1
           J2=MOD(MCON(I2,II)-1,NX)+1
           IF(MCON(I1,II).LE.NX.AND.MCON(I2,II).LE.NX) THEN
C  LOWER BOUNDARY
             MCON(JJ,II)=0
           ELSE IF(MCON(I1,II).GT.NTOT-NX.AND.MCON(I2,II).GT.NTOT-NX) T
     +     HEN
C  UPPER BOUNDARY
             MCON(JJ,II)=-1
           ELSE IF(J1.EQ.1.AND.J2.EQ.1) THEN
C  LEFT END
             MCON(JJ,II)=-2
           ELSE IF(J1.EQ.NX.AND.J2.EQ.NX) THEN
C  RIGHT END
             MCON(JJ,II)=-3
           ENDIF
```

```
 80    CONTINUE
C
C  CONNECT FIXED POTENTIALS FROM MCON
       DO 90 II=1,NBDY-1
         IPT=MBDY(1,II)
         DO 100 JJ=1,NEL
           DO 110 KK=1,3
             IF(MCON(KK,JJ).EQ.IPT) THEN
               IP=MOD(KK,3)+1
               JP=MOD(IP,3)+1
               DO 120 LL=II+1,NBDY
                 IF(MBDY(2,LL).EQ.MBDY(2,II)) THEN
                   IF(MCON(IP,JJ).EQ.MBDY(1,LL)) MCON(JP+3,JJ)=MBDY(2,LL)
                   IF(MCON(JP,JJ).EQ.MBDY(1,LL)) MCON(IP+3,JJ)=MBDY(2,LL)
                 ENDIF
 120           CONTINUE
               GO TO 100
             ENDIF
 110       CONTINUE
 100     CONTINUE
 90    CONTINUE
C
C  REMOVE -99. MARKED FIXED VOLTAGES.
       JJ=0
       DO 140 II=1,NBDY
         IF(VP(II).NE.-99.) THEN
           JJ=JJ+1
           MBDY(1,JJ)=MBDY(1,II)
           MBDY(2,JJ)=MBDY(2,II)
           VP(JJ)=VP(II)
         ENDIF
 140   CONTINUE
       NBDY=JJ
C
C  CALCULATE AREAS OF TRIANGLES
       DO 130 II=1,NEL
         CALL ACRDS(0.D0,0.D0,0.D0,II,XX,YY,VV,MCON,AINV,ANEL(II),ASUM)
 130   CONTINUE
C
       RETURN
       END
       SUBROUTINE ACRDS(VPRP,XPT,YPT,NIE,XX,YY,VV,MCON,BINV,AREA,ASUM)
       IMPLICIT REAL*8 (A-H,O-Z)
       DIMENSION XX(*),YY(*),AINV(3,5),BINV(3,5),MCON(7,*),
      +XE(3),YE(3),VV(*)
       DOUBLE PRECISION A2,XE,YE,AINV
C
       ZRO=1.E-9
       DO 10 I=1,3
         XE(I)=XX(MCON(I,NIE))
         YE(I)=YY(MCON(I,NIE))
 10    CONTINUE
C
       AINV(1,1)=XE(2)*YE(3)-XE(3)*YE(2)
       AINV(2,1)=XE(3)*YE(1)-XE(1)*YE(3)
       AINV(3,1)=XE(1)*YE(2)-XE(2)*YE(1)
       A2=AINV(1,1)+AINV(2,1)+AINV(3,1)
       AREA=A2/2.
       AINV(1,1)=AINV(1,1)/A2
       AINV(2,1)=AINV(2,1)/A2
```

```
      AINV(3,1)=AINV(3,1)/A2
C
      AINV(1,2)=(YE(2)-YE(3))/A2
      AINV(2,2)=(YE(3)-YE(1))/A2
      AINV(3,2)=(YE(1)-YE(2))/A2
      AINV(1,3)=(XE(3)-XE(2))/A2
      AINV(2,3)=(XE(1)-XE(3))/A2
      AINV(3,3)=(XE(2)-XE(1))/A2
C
      AINV(1,5)=0.
      AINV(2,5)=0.
      AINV(3,5)=0.
      DO 20 I=1,3
        AINV(I,4)=AINV(I,1)+AINV(I,2)*XPT+AINV(I,3)*YPT
        DO 20 J=2,4
          II=MCON(I,NIE)
          AINV(J-1,5)=AINV(J-1,5)+AINV(I,J)*(VV(II)+(VPRP/MAX(.001,ABS(
     -    YY(II)))))**2)
 20   CONTINUE
C
      ASUM=0.
      DO 30 I=1,3
        IF(ABS(AINV(I,4)).LT.ZRO) AINV(I,4)=0.
        IF(ABS(AINV(I,5)).LT.ZRO) AINV(I,5)=0.
        ASUM=ASUM+ABS(AINV(I,4))
 30   CONTINUE
      DO 40 II=1,5
        DO 40 JJ=1,3
          BINV(JJ,II)=AINV(JJ,II)
 40   CONTINUE
C
      RETURN
      END
      SUBROUTINE CLP2D(DEBYE,SK,VV,CHD,VP,NTOT,NBDW,NEL,NBDY,MBDY,XX,YY,
     +MCON,ANEL,ENOT)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SK(NBDW,NTOT),VV(NTOT),CHD(NEL),VP(NBDY),XX(NTOT),
     +YY(NTOT),ANEL(NEL),MBDY(2,NBDY),MCON(7,NEL)
      TVOLTS=ABS(ENOT)
      IFAXIS=3
      DO 10 II=1,NBDY
        VP(II)=VP(II)/TVOLTS
 10   CONTINUE
C
C  SET RIGHT HAND SIDE
      CALL SETQ2(NTOT,NEL,DEBYE,VV,CHD,ANEL,MCON)
C
C  SET SK
      CALL SETK0(NTOT,NBDW,NEL,IFAXIS,MCON,SK,XX,YY,ANEL)
C
C  IMPOSE ESSENTIAL B.C.
      CALL ESSBC(SK,VV,VP,NBDY,MBDY,NTOT,NBDW)
C
C  SOLVE
      CALL SOLV(SK,VV,NTOT,NBDW)
C
C  CONVERT FROM KT TO VOLTS
      DO 20 I=1,NTOT
        IF(ABS(VV(I)).LT.1.E-9) VV(I)=0.
        VV(I)=VV(I)*TVOLTS
```

```
         IF(I.LE.NBDY) VP(I)=VP(I)*TVOLTS
 20    CONTINUE
       RETURN
       END
       SUBROUTINE TRAJ(BINV,VPRP,KSTEP,XSGN,YSGN,VV,XX,YY,IPRT,NTRJ,
      -NEL,MCON,IEND,LOC,TAU,IFPLT,RB,AEND,EGYE,BETE,RPE)
       IMPLICIT REAL*8 (A-H,O-Z)
       DIMENSION MCON(7,*),VV(*),XX(*),YY(*),TAU(*),AINV(3,5),
      -PLT(2,51),BINV(3,5)
       COMMON /ORB/ XDOT,YDOT,XP,YP,NTSAV,TIMIN,NOWEL,NOWSD
       COMMON /INST/ RIP,ROP,RIA,ROA,ENOT,EGZ
       SAVE
       DATA ICALL /0/
       IF(ICALL.EQ.0) THEN
         ICALL=1
         PI=ACOS(-1.)
         RTOD=180./PI
C        CALL SSWTCH(2,ISW2)
         ISW2=2
         RKON=(1./RIP-1./ROP)
         EKON=ENOT*(ROP+RIP)*RKON
         VINN=EKON/(1.+RIP/ROP)
         VOUT=VINN-EKON
       ENDIF
C
       PLT(1,51)=0.
       PLT(2,51)=0.
       NPT=0
       KSTEP=0
       KSMX=1000
       YSGN=1.
       XSGN=1.
       ERMX=0.
       RP=SQRT(XP*XP+YP*YP)
       ALP=ATAN2(YP,XP)*RTOD
       IF(ALP.GT.150.) ALP=ALP-360.
       BET=90.+ATAN2(YDOT,XDOT)*RTOD-ALP
       IF(BET.GT.90.) BET=BET-360.
       IF(BET.LT.-90.) BET=BET+360.
       EGY=XDOT*XDOT+YDOT*YDOT
       IF(IPRT.NE.0) THEN
         WRITE(6,3002)
         WRITE(6,3001) KSTEP,NOWEL,NOWSD,XP,YP,XDOT,YDOT,BINV(3,5),IEND,
     +   0,0,0.,RP,ALP,EGY,BET
 3001    FORMAT(1X,I4,I4,I3,2F8.4,2F8.2,F8.4,I4,2I4,F8.4,F10.4,2F8.2,F8.4
     +)
 3002    FORMAT(//3X,'KS NIE NSD     X        Y',6X,'      ,4X,'YDOT',
     +   5X,'PHI',2X,'IE IND LOC      T',9X,'R',"          ',5X,'EGY',4X,'BET'
     +   )
       ENDIF
C
C  CHECK FOR REFLECTIVE INJECTION
         INDSV=1
         LOC=0
C  NOT NOW USING Y=0 SYMMETRY PLANE
C        IF(YDOT.GE.0..OR.YY.NE.0.) GO TO 60
C        YSGN=-1.
C        YDOT=-YDOT
C
 60      CONTINUE
```

```
C  NOT NOW USING X=0 SYMMETRY PLANE
C      IF(XDOT.GE.0..OR.XP.NE.0.) GO TO 10
C      XSGN=-1.
C      XDOT=-XDOT
C
 10    CONTINUE
       NEXEL=MCON(NOWSD+3,NOWEL)
       IF(KSTEP.NE.0) THEN
         DO 30 IS=1,3
           IF(MCON(IS+3,NEXEL).EQ.NOWEL) NOWSD=IS
 30      CONTINUE
         NOWEL=NEXEL
       ENDIF
C
 20    CONTINUE
       IERR=0
       CALL ORBIT2(AINV,IPRT,VPRP,KSTEP,MCON,NEL,VV,XX,YY,NTRJ,IEND,
      +LOC,ERMX,BINV)
       KSTEP=KSTEP+1
       IF(IFPLT.NE.0) THEN
         NPT=NPT+1
         PLT(1,NPT)=XP
         PLT(2,NPT)=YP
         IF(IFPLT.EQ.2) THEN
           PLT(1,NPT)=ATAN2(YP,XP)*RTOD
           PLT(2,NPT)=SQRT(XP*XP+YP*YP)
           IF(PLT(1,NPT).GT.90.) PLT(1,NPT)=PLT(1,NPT)-360.
         ENDIF
         IF(NPT.EQ.50) THEN
           WRITE(8) 2,51,PLT
           NPT=1
           PLT(1,1)=PLT(1,50)
           PLT(2,1)=PLT(2,50)
         ENDIF
       ENDIF
       INDIC=MCON(NOWSD+3,NOWEL)
       JPRT=0
       IF(IPRT.EQ.1.OR.(IPRT.GT.1.AND.INDIC.LE.0)) JPRT=1
       IF(ABS(XP).LT.1.E-6.OR.ABS(YP).LT.1.E-6.OR.INDIC.LE.0) THEN
         RP=SQRT(XP*XP+YP*YP)
         ALP=ATAN2(YP,XP)*RTOD
         IF(ALP.GT.150.) ALP=ALP-360.
         BET=90.+ATAN2(YDOT,XDOT)*RTOD-ALP
         IF(BET.GT.90.) BET=BET-360.
         IF(BET.LT.-90.) BET=BET+360.
         EGY=XDOT*XDOT+YDOT*YDOT
         IF(ABS(ALP-AEND).LT.1.E-6) THEN
           RPE=RP
           EGYE=EGY
           BETE=BET
         ENDIF
         IF(IPRT.EQ.2) JPRT=1
       ENDIF
       IF(JPRT.EQ.1) THEN
         WRITE(6,3001) KSTEP,NOWEL,NOWSD,XP*XSGN,YP*YSGN,XDOT*XSGN,YDOT
      +  *YSGN,BINV(3,5),IEND,INDIC,LOC,TIMIN,RP,ALP,EGY,BET
       ENDIF
       TAU(NOWEL)=TAU(NOWEL)+TIMIN
       IF(LOC.EQ.0) INDSV=1
C
```

```
      IF(IEND.EQ.-1) GO TO 90
      IF(IEND.LT.0) GO TO 110
      IF(KSTEP.EQ.KSMX) GO TO 50
      IF(INDIC.EQ.-1) GO TO 100
      IF(INDIC.GT.0) GO TO 10
C
      IF(LOC.NE.0.AND.(INDIC.EQ.0.OR.INDIC.EQ.-2)) THEN
        IF(INDIC.EQ.INDSV) GO TO 90
        INDSV=INDIC
        NOWSD=NTSAV
        GO TO 20
      ENDIF
C
C  END-OF-TRAJECTORY
      IEND=INDIC
      GO TO 110
C
 100  CONTINUE
      IF(ABS(XP).LE.1.E-6) THEN
C  Y-AXIS REFLECTION
        XSGN=-XSGN
        XDOT=-XDOT
      ELSE IF(ABS(YP).LE.1.E-6) THEN
C  X-AXIS REFLECTION
        YSGN=-YSGN
        YDOT=-YDOT
      ELSE
        GO TO 40
      ENDIF
      NOWSD=NTSAV
      GO TO 20
C
 50   CONTINUE
C  TOO MANY STEPS.  TREAT AS ABSORPTION.
C     WRITE(7,*)  ' ORBIT STEPS KSTEP,KSMX = ',KSTEP,KSMX
      IEND=-3
      GO TO 110
C
 40   CONTINUE
C     WRITE(7,*) '  ORBIT ERROR.  NTRJ = ',NTRJ
      IEND=-3
      GO TO 110
C
C  INJECTION INTO BODY.  TREAT AS ABSORPTION
 90   CONTINUE
      IEND=-2
      IF(INDSV.LE.0) IEND=INDSV
C
 110  CONTINUE
      IF(IEND.EQ.-9) THEN
        DALP=ALP
        DO 120 II=1,3
          KSTEP=KSTEP+1
          CALL ELLPS(EGY,RP,BET,ALP,DALP,EGYE,RPE,BETE,ALPE,LTEST)
          INDIC=-LTEST
C         WRITE(6,3001) KSTEP,NOWEL,NOWSD,XP*XSGN,YP*YSGN,XDOT*XSGN,YDOT
C    +    *YSGN,BINV(3,5),IEND,INDIC,LOC,TIMIN,RPE,ALPE,EGYE,BETE
          ALP=ALPE
          DALP=90.
          RP=RPE
```

```
          EGY=EGYE
          BET=BETE
          IF(LTEST.NE.1) GO TO 130
120     CONTINUE
130   CONTINUE
      ENDIF
      IF(ISW2.EQ.1) WRITE(6,3001) KSTEP,NOWEL,NOWSD,XP*XSGN,YP*YSGN,
     +XDOT*XSGN,YDOT*YSGN,BINV(3,5),IEND,INDIC,LOC,TIMIN
      IF(NPT.GT.1) WRITE(8) 2,NPT+1,((PLT(I,J),I=1,2),J=1,NPT),0.,0.
      MTEST=1.
      IF(ALP-1.E-6.GT.AEND) THEN
        IF(ABS(ALP+90.).LT.1.E-6) THEN
          MTEST=4
        ELSE IF(ALP.GT.-90.) THEN
          MTEST=2
        ELSE
          MTEST=6
        ENDIF
        IF(RP.LT.(RIP+ROP)/2.) MTEST=MTEST+1
      ENDIF
      IEND=MTEST
      RETURN
      END
      SUBROUTINE ORBIT2(AINV,IPRT,VPRP,KSTEP,MCON,NEL,VV,XX,YY,NTRJ,
     +KERR,LOC,ERMX,BINV)
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     DETERMINATION OF PHIX, PHIY, AT X, Y FOR NEXEL
C
      COMMON /ORB/ XDOT,YDOT,XP,YP,NTSAV,TIMIN,NOWEL,NOWSD
      DOUBLE PRECISION ROOT,RADIC,TM,UD,UDD,ADD,D,DZRO,T,TIMN,XD,YD,
     +XNEW,YNEW,DYP,DXP
      DIMENSION MCON(7,*),VV(*),XX(*),YY(*)
      DIMENSION T(6),D(3),UD(3),UDD(3)
      DIMENSION AINV(3,5),BINV(3,5)
      SAVE
      DATA IER,ICALL /2*0/
      IF(ICALL.EQ.0) THEN
        LOC=0
        ICALL=1
      ENDIF
C
      IE=NOWEL
      TIMIN=0.
      TIMN=0.
      CALL ACRDS(VPRP,XP,YP,NOWEL,XX,YY,VV,MCON,AINV,AREA,ASUM)
      XD=XDOT
      YD=YDOT
      DXP=XP
      DYP=YP
      KERR=0
      IALT=0
      NTSAV=NOWSD
C
C    STEP ACROSS 2-D TRIANGLE ASSUMING CONSTANT POTENTIAL WITHIN TRIANGLE
C        INCLUDING ACCELERATION TERMS
C
C
      TOOM=3.3333E+33
      ZRO=1.E-9
```

```
      DZRO=1.D-15
C
      XDD=.5*AINV(1,5)
      YDD=.5*AINV(2,5)
C
 70   CONTINUE
      DO 10 I=1,3
        D(I)=AINV(I,4)
        UD(I)=AINV(I,2)*XDOT+AINV(I,3)*YDOT
        UDD(I)=AINV(I,2)*XDD+AINV(I,3)*YDD
 10   CONTINUE
C
      ISID=0
      DO 50 K=1,3
        IF(D(K).LT.ZRO) D(K)=0.
        IF(ABS(UD(K)).LT.ZRO) UD(K)=0.
        IF(UDD(K)*UDD(K).LT.DZRO) UDD(K)=0.
        IF(D(K).EQ.0..AND.K.NE.NOWSD) THEN
          IF(NOWSD.NE.0) ISID=K
          IF(NOWSD.EQ.0) NOWSD=K
        ENDIF
 50   CONTINUE
      IF(ISID.GT.0.AND.NOWSD.GT.0) THEN
        IF(UD(NOWSD).LT.0..OR.(UD(NOWSD).EQ.0..AND.UDD(NOWSD).LT.0.).OR.
     +  UD(ISID).LT.0..OR.(UD(ISID).EQ.0..AND.UDD(ISID).LT.0.)) THEN
          NEXEL=MCON(ISID+3,NOWEL)
          IF(LOC.GE.10) WRITE(7,*) '  LOC,NOWEL,NOWSD,ISID,NEXEL,UD = ',
     +    LOC,NOWEL,ISID,NEXEL,UD(NOWSD),UD(ISID)
          IF(LOC.LE.16) THEN
            LOC=LOC+1
            NTSAV=ISID
            NOWSD=ISID
          ELSE
            KERR=-1
            LOC=0
          ENDIF
          RETURN
        ENDIF
      ENDIF
C
      LOC=0
      DO 20 K=1,3
        IF(D(K).NE.0..OR.UD(K).GT.0..OR.ISID.NE.0) GO TO 20
        IF(KSTEP.EQ.0) RETURN
        UD(K)=1.E-4
        IF(AINV(K,2).EQ.0.) GO TO 30
        XD=(UD(K)-AINV(K,3)*YDOT)/AINV(K,2)
        XDOT=XD
        GO TO 70
C
 30     CONTINUE
        IF(AINV(K,3).NE.0.) YD=(UD(K)-AINV(K,2)*XDOT)/AINV(K,3)
        IF(AINV(K,3).NE.0.) YDOT=YD
 20   CONTINUE
C
C     IF(IER.EQ.1) WRITE(6,3001) D,UD
 3001 FORMAT(5X,'D,UD = ',2(3F10.6,2X))
C
      NTSAV=-9
      TIMN=TOCM
```

```
      DO 500 K=1,3
        K2=2*K
        K1=K2-1
        T(K1)=TCOM
        T(K2)=TCOM
        RCOT=0.
        IF(UDD(K).EQ.0..AND.UD(K).EQ.0.) GO TO 500
        IF(UDD(K).NE.0..OR.UD(K).EQ.0.) GO TO 100
        TM=-D(K)/UD(K)
        GO TO 200
C
 100    CONTINUE
        TM=-UD(K)/UDD(K)
        ADD=-2.*D(K)/UDD(K)
        RADIC=TM*TM+ADD
        IF(RADIC.LT.-DZRO) GO TO 500
        IF(RADIC.GT.DZRO) RCOT=DSQRT(RADIC)
C
 200    CONTINUE
C       IF(K.EQ.1) WRITE(7,*) '  TM,ADD,RADIC,RCOT,T = ',TM,ADD,RADIC,
C    +  RCOT,T(K1),T(K2)
        T(K1)=TM-RCOT
        T(K2)=TM+RCOT
 500  CONTINUE
C
C  FIND SHORTEST TIME AND SAVE COORDS.
C
      DO 400 L=1,6
        NT=(L-1)/2+1
        IF(T(L).LT.0..OR.T(L).GE.TIMN) GO TO 400
        IF((NT.EQ.NOWSD.OR.NT.EQ.ISID).AND.T(L).LE.ZRO) GO TO 400
C       WRITE(7,*) 'NT,NOWSD,ISID,TIMN,T(L) = ',NT,NOWSD,ISID,TIMN,T(L)
        NTSAV=NT
        TIMN=T(L)
 400  CONTINUE
      TIMIN=TIMN
      IF(KERR.EQ.1) WRITE(7,*) ' T =',T
      XNEW=-1.
      YNEW=-1.
      BSUM=-1.
      XDOT=-1.
      YDOT=-1.
C
      IF(NTSAV.LT.0) GO TO 700
C
C  ADVANCE THROUGH MINIMUM TIME TIMN
      IERR=0
      XNEW=DXP+XD*TIMN+.5*XDD*TIMN*TIMN
      YNEW=DYP+YD*TIMN+.5*YDD*TIMN*TIMN
      XT=XNEW
      YT=YNEW
C
C  CHECK PRECISION OF FINAL DESTINATION
C
      CALL ACRDS(0.D0,XT,YT,NOWEL,XX,YY,VV,MCON,BINV,AREA,BSUM)
      ERMX=MAX(ABS(BSUM)-1.,ERMX)
      IF(BSUM.GT.1.+25.*ZRO) IERR=1
C
C  FINISH UP
C
```

```
      XDOT=XD+XDD*TIMN
      YDOT=YD+YDD*TIMN
      IF(IERR.NE.0) GO TO 700
C
C     SET UP BOOKKEEPING FOR ADVANCE TO NEXT TRIANGLE
      NOWSD=NTSAV
      XP=XNEW
      YP=YNEW
      IF(ABS(XP).LT.ZRO) XP=0.
      IF(ABS(YP).LT.ZRO) YP=0.
      IF(ABS(XDOT).LT.ZRO) XDOT=0.
      IF(ABS(YDOT).LT.ZRO) YDOT=0.
C
      RETURN
 700  CONTINUE
      IER=1
      WRITE(6,2001) IERR,IE,NOWSD,NTSAV,ISID,LOC,NTRJ
 2001 FORMAT(//5X,'PROBLEM IN ORBIT2 WITH IERR,IE,NOWSD,NTSAV,ISID,LOC =
     +',6I3,'NTRJ = ',I7)
      WRITE(6,2002) XP,YP,XD,YD,XDD,YDD,XNEW,YNEW,XDOT,YDOT,D,UD,UDD,
     +(AINV(I,4),I=1,3),ASUM-1.,(BINV(I,4),I=1,3),BSUM-1.
 2002 FORMAT(/5X,'INITIAL X,Y,XDOT,YDOT,XDD,YDD = ',6F12.6/
     +5X,'  FINAL X,Y,XDOT,YDOT = ',4F12.6/
     +5X,'D VECTOR    = ',1P3E12.4/
     +5X,'UD VECTOR   = ',3E12.4/
     +5X,'UDD VECTOR  = ',3E12.4/
     +5X,'A VECTOR    = ',3E12.4,'  ASUM-1. = ',E12.4/
     +5X,'B VECTOR    = ',3E12.4,'  BSUM-1. = ',E12.4)
      IF(NTSAV.GT.0) WRITE(6,2003) T,TIMN
      IF(NTSAV.LE.0) WRITE(6,2003) T,-1.
 2003 FORMAT(5X,'T VECTOR = ',1P6E12.4/5X,'SELECTED TIMN = ',E14.6)
      KERR=-3
C     WRITE(6,*) '  ORBIT2 ERROR.  TRAJECTORY NO = ',NTRJ
C     CALL DISCON(M)
      RETURN
      END
      SUBROUTINE GEOMB(VOUT,VINN,RIP,ROP,RIA,ROA,ENOT,NX,NY,NBDY,XX,YY,
     +VV,CHD,VP,MBDY,PP,RR,IAP,AEND,IPRT,IBK,NBK)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION XX(*),YY(*),VV(*),RR(*),IN(65),XA(65),XT(65),RA(65),
     +YT(65),CHD(*),VP(*),MBDY(2,*),PP(*),IAP(4,4),PA(65),IBK(*)
      CHARACTER*80 IHED
C
      RTOD=180./ACOS(-1.)
C
C  READ INSTRUMENT HEADER CARD
      READ(4,'(A80)',END=100) IHED
      WRITE(6,'(1H1//5X,A)') IHED
C
C  READ LOGIC CARD
      READ(4,2001,END=100) NX,NY,NL,NV,NIA,NOA,NCA,IPRT
 2001 FORMAT(4I5,2X,3I1,I5)
C
C  READ INPUT APERTURE CARD
      READ(4,*,END=100) IAP
C
C  READ R CARD INPUT AND EXPAND
      READ(4,*,END=100) NRP,(IN(I),RA(I),I=1,NRP)
      CALL VEXP(NRP,IN,RA)
C
```

```
      RIP=RA(IAP(3,2))
      ROP=RA(IAP(4,2))
      RIA=RA(IAP(3,1))
      ROA=RA(IAP(4,1))
      WRITE(6,'(12X,''DIAMETER OF ENTRANCE APERTURE = '',F7.3,'' CM'')')
     -ROA-RIA
      WRITE(6,'(5X,''INNER AND OUTER RADIUS OF INSTRUMENT = '',2F7.3,
     -'' CM'')') RIP,ROP
      WRITE(6,'(8X,''INNER AND OUTER RADIUS AT 180 DEG = '',2F7.3
     -)') RA(IAP(3,3)),RA(IAP(4,3))
      WRITE(6,'(7X,''INNER AND OUTER RADIUS AT EXIT APP = '',2F7.3
     -)') RA(IAP(3,4)),RA(IAP(4,4))
C
      RKON=(1./RIP-1./ROP)
      EKON=ENOT*(ROP+RIP)*RKON
      VINN=EKON/(1.+RIP/ROP)
      VOUT=VINN-EKON
C
C  READ ALPHA INPUT CARD AND EXPAND
      READ(4,*,END=100) NAP,(IN(I),PA(I),I=1,NAP)
      CALL VEXP(NAP,IN,PA)
      AEND=PA(NX)
      WRITE(6,'(19X,''ANGULAR LENGTH OF TUBE = '',F7.1,'' DEG'')') 90.-
     +AEND
C
C  READ BASE LEVEL CARD AND EXPAND
      READ(4,*,END=100) NXP,(IN(I),XA(I),I=1,NXP)
      CALL VEXP(NXP,IN,XA)
C
C  DO ALPHA EXPANSION OF XA
      RTOD=180./ACOS(-1.)
      DO 10 II=1,NX
      IF(PA(II).EQ.90..OR.PA(II).EQ.-90.) THEN
        XX(II)=XA(II)
        YY(II)=RA(1)
        IF(PA(II).EQ.-90.) YY(II)=-RA(1)
        RR(II)=SQRT(XX(II)**2+YY(II)**2)
        PP(II)=ATAN2(YY(II),XX(II))*RTOD
      ELSE
        XX(II)=RA(1)*COS(PA(II)/RTOD)
        YY(II)=RA(1)*SIN(PA(II)/RTOD)
        RR(II)=RA(1)
        PP(II)=PA(II)
      ENDIF
      IF(PP(II).GT.180.) PP(II)=PP(II)-360.
 10   CONTINUE
C
C  READ TOP LEVEL CARD AND EXPAND
      READ(4,*,END=100) NXP,(IN(I),XA(I),I=1,NXP)
      CALL VEXP(NXP,IN,XA)
C
C  DO ALPHA EXPANSION OF XA
      DO 20 II=1,NX
        IF(PA(II).EQ.90..OR.PA(II).EQ.-90.) THEN
          XT(II)=XA(II)
          YT(II)=RA(NY)
          IF(PA(II).EQ.-90.) YT(II)=-RA(NY)
        ELSE
          XT(II)=RA(NY)*COS(PA(II)/RTOD)
          YT(II)=RA(NY)*SIN(PA(II)/RTOD)
```

```
        ENDIF
 20   CONTINUE
C
C  EXPAND GRID FROM BOTTOM TO TOP LEVELS
      NN=NX
      DO 30 II=2,NY
        RTIO=(RA(II)-RA(1))/(RA(NY)-RA(1))
        DO 40 JJ=1,NX
          NN=NN+1
          XX(NN)=XX(JJ)+RTIO*(XT(JJ)-XX(JJ))
          YY(NN)=YY(JJ)+RTIO*(YT(JJ)-YY(JJ))
          PP(NN)=ATAN2(YY(NN),XX(NN))*RTCD
          IF(ABS(XX(NN)).LT.1.E-10) XX(NN)=0.
          IF(ABS(YY(NN)).LT.1.E-10) YY(NN)=0.
          IF(ABS(PP(NN)).LT.1.E-10) PP(NN)=0.
          IF(PP(NN).GT.150.) PP(NN)=PP(NN)-360.
          RR(NN)=SQRT(XX(NN)**2+YY(NN)**2)
 40     CONTINUE
 30   CONTINUE
C
C  READ FIXED VOLTAGE CARDS
      NBDY=0
      NTOT=NX*NY
      NEL=(NX-1)*(NY-1)*2
      NBK=0
      DO 80 II=1,NEL
        IF(II.LE.NTOT) VV(II)=0.
        CHD(II)=0.
 80   CONTINUE
      DO 50 II=1,NV
        READ(4,*,END=100) VF,I1,I2,J1,J2,ILB
        IF(II.EQ.1) VF=VINN
        IF(II.EQ.2) VF=VOUT
        IF(ILB.EQ.9) THEN
          NBK=NBK+1
          IBK(NBK)=I1
        ENDIF
        DO 60 JJ=J1,J2
          DO 70 KK=I1,I2
            NBDY=NBDY+1
            NN=NX*(JJ-1)+KK
            MBDY(1,NBDY)=NN
            MBDY(2,NBDY)=-ILB
            IF(ILB.EQ.9) THEN
              VP(NBDY)=VINN-EKON/RKON*(1./RIP-1./RR(NN))
              VV(NN)=VP(NBDY)
            ELSE
              VP(NBDY)=VF
              VV(NN)=VF
            ENDIF
 70       CONTINUE
 60     CONTINUE
 50   CONTINUE
      RETURN
 100  CONTINUE
      STOP 'NXTIN'
      END
      SUBROUTINE VEXP(NRP,IN,RR)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION IN(*),RR(*)
```

```
      DO 10 II=NRP,2,-1
        RR(IN(II))=RR(II)
        DR= RR(II)-RR(II-1))/FLOAT(IN(II)-IN(II-1))
        DO 20 JJ=IN(II)-1,IN(II-1)+1,-1
          RR(JJ)=RR(JJ+1)-DR
20      CONTINUE
10    CONTINUE
      RETURN
      END
      SUBROUTINE ELLPS(EGI,RRI,BEI,THI,DEL,EGO,RRO,BEO,THO,ITEST)
      IMPLICIT REAL*8 (A-H,O-Z)
      LOGICAL QMX,QMN,QTP,QBT,QTC,QBC,QEX
      COMMON /INST/ RIP,ROP,RIA,ROA,ENOT,EGZ
      SAVE
      DATA NCALL /0/
      IF(NCALL.EQ.0) THEN
        PI=ACOS(-1.)
        PI32=1.5*PI
        RTOD=180./PI
        NCALL=1
        RKON=(1./RIP-1./ROP)
        EKON=ENOT*(ROP+RIP)*RKON
        VINN=EKON/(1.+RIP/ROP)
        VOUT=VINN-EKON
        QQ=EKON/RKON
      ENDIF
      THE=90.-THI
      RDEL=DEL/RTOD
      TBET=TAN(BEI/RTOD)
      RTHE=THE/RTOD
      EKC=QQ/(2.*RRI)
      CC=EKC/EGI/COS(BEI/RTOD)**2
      UURT=CC-TBET*SIN(RDEL)+(1.-CC)*COS(RDEL)
      RR=RRI/UURT
      PMAX=PI/2.
      IF(CC.NE.1.) PMAX=-ATAN(TBET/(1.-CC))
      UUPM=CC-TBET*SIN(PMAX)+(1.-CC)*COS(PMAX)
      UUQM=CC+TBET*SIN(PMAX)-(1.-CC)*COS(PMAX)
      U180=CC-TBET*SIN(PI-RTHE)+(1.-CC)*COS(PI-RTHE)
      U270=CC-TBET*SIN(PI32-RTHE)+(1.-CC)*COS(PI32-RTHE)
      RMAX=RRI/UUPM
      RMIN=RRI/UUQM
      R180=RRI/U180
      R270=RRI/U270
      PMAX=PMAX*RTOD+THE
      IF(PMAX.LT.0.) PMAX=PMAX+360.
      IF(PMAX.GT.360.) PMAX=PMAX-360.
C
C  ITEST LOGIC
      IF(RMAX.GT.RMIN) THEN
        PMIN=PMAX+180.
      ELSE
        RT=RMAX
        RMAX=RMIN
        PT=PMAX
        PMAX=PMAX+180.
        RMIN=RT
        PMIN=PT
      ENDIF
      IF(PMAX.LT.0.) PMAX=PMAX+360.
```

```
      IF(PMIN.LT.0.) PMIN=PMIN+360.
      IF(PMAX.GT.360.) PMAX=PMAX-360.
      IF(PMIN.GT.360.) PMIN=PMIN-360.
      QMX=PMAX.GT.THE.AND.PMAX.LE.THE+DEL.AND.RMAX.GE.ROP
      QMN=PMIN.GT.THE.AND.PMIN.LE.THE+DEL.AND.RMIN.LE.RIP
      IF(QMX.AND.QMN) THEN
        QMX=QMX.AND.PMAX.LT.PMIN
        QMN=.NOT.QMX
      ENDIF
      QTP=QMX.OR.RRI.GT.ROP.OR.RR.GE.ROP
      QBT=QMN.OR.RRI.LT.RIP.OR.RR.LE.RIP
      QTC=THE.LT.180..AND.THE+DEL.GE.180..AND.R180.GE.ROA.AND.R180.LT.
     +ROP
      QBC=THE.LT.180..AND.THE+DEL.GE.180..AND.R180.LE.RIA.AND.R180.GT.
     +RIP
      QEX=THE.LT.270..AND.THE+DEL.GE.270.AND.R270.LT.ROP.AND.R270.GT.RIP
C
      ZTHE=RDEL
      TT1=MIN(MAX(0.,RDEL),PI-RTHE)
      TT2=MIN(MAX(PI-RTHE,DEL),PI32-RTHE)
      IF(QTP.OR.QTC) THEN
C  HITS TOP PLATE WITHEN THE + DEL INTERVAL
          IF(QTP.AND.(PMAX.LE.180..OR.R180.GT.ROA)) THEN
            ITEST=2
            CALL NEWT(CC,TBET,TT1,RRI,ROP,ZTHE)
          ELSE IF(QTC) THEN
            ITEST=4
            ZTHE=PI-RTHE
          ELSE
            ITEST=6
            CALL NEWT(CC,TBET,TT2,RRI,ROP,ZTHE)
          ENDIF
        ELSE IF(QBT.OR.QBC) THEN
C  HITS BOTTOM PLATE WITHEN INTERVAL
          IF(QBT.AND.(PMIN.LE.180..OR.R180.LT.RIA)) THEN
            ITEST=3
            CALL NEWT(CC,TBET,TT1,RRI,RIP,ZTHE)
          ELSE IF(QBC) THEN
            ITEST=5
            ZTHE=PI-RTHE
          ELSE
            ITEST=7
            CALL NEWT(CC,TBET,TT2,RRI,RIP,ZTHE)
          ENDIF
        ELSE
          ITEST=1
        ENDIF
        UURT=CC-TBET*SIN(ZTHE)+(1.-CC)*COS(ZTHE)
        BEIN=(1.-CC)*SIN(ZTHE)+TBET*COS(ZTHE)
        BEO=0.
        IF(UURT.NE.0.) BEO=ATAN(BEIN/UURT)*RTOD
        IF(BEO.GT.90.) BEO=BEO-360.
        IF(BEO.LT.-90.) BEO=BEO+360.
        RRO=RRI/UURT
        THO=THI-ZTHE*RTOD
        EGO=EGZ+VINN-EKON/RKON*(1./RIP-1./RRO)
        RETURN
        END
        SUBROUTINE FWHM(NE,IESM,EKST,EKINC,EBAR,SIG,ERAN)
        IMPLICIT REAL*8 (A-H,O-Z)
```

```
      DIMENSION IESM(*)
      MAXX=IESM(1)
C
C  DETERMINE EBAR, SIGMA
      NN=0
      EBAR=0.
      SIG=0.
      YSUM=0
      SQSM=0.
      DO 10 II=1,NE
        NN=NN+IESM(II)
        YY=EKST+(II-1)*EKINC
        YSUM=YSUM+YY*IESM(II)
        SQSM=SQSM+YY*YY*IESM(II)
 10   CONTINUE
      IF(NN.GE.3) THEN
        EBAR=YSUM/NN
        SIG=(SQSM-EBAR*EBAR*NN)/(NN-1)
        IF(SIG.GT.0.) SIG=SQRT(SIG)
      ENDIF
      MAXCH=1
      MAXX=IESM(1)
      DO 50 I=2,NE
        IF(IESM(I).GT.MAXX) THEN
          MAXX=IESM(I)
          MAXCH=I
        ENDIF
 50   CONTINUE
      HMAX=FLOAT(MAXX)/2.
      CH1=0.
      CH2=NE
      DEN=1.
      DO 60 I=1,MAXCH
        IF(HMAX.GT.FLOAT(IESM(I)).AND.HMAX.LE.FLOAT(IESM(I+1))) THEN
          DEN=IESM(I+1)-IESM(I)
          IF(ABS(DEN).LT.1.E-6) DEN=1.
          CH1=I-1+(HMAX-FLOAT(IESM(I)))/DEN
        ENDIF
 60   CONTINUE
      DO 70 I=NE,MAX(2,MAXCH),-1
        IF(HMAX.GT.FLOAT(IESM(I)).AND.HMAX.LE.FLOAT(IESM(I-1))) THEN
          DEN=IESM(I-1)-IESM(I)
          CH2=I-1-(HMAX-FLOAT(IESM(I)))/DEN
        ENDIF
 70   CONTINUE
      CCH1=EKST+CH1*EKINC
      CCH2=EKST+CH2*EKINC
      ERAN=(CH2-CH1)*EKINC
      RETURN
      END
      SUBROUTINE NEWT(CC,TBET,DEL,RRI,RRT,THE)
      IMPLICIT REAL*8 (A-H,O-Z)
      UU(TT)=CC-TBET*SIN(TT)+(1.-CC)*COS(TT)-URRT
      UP(TT)=-TBET*COS(TT)-(1.-CC)*SIN(TT)
      IFRTY=0
      GSS=4.
 40   CONTINUE
      URRT=RRI/RRT
      XPP=DEL/GSS
      YPP=UU(XPP)
```

```
      DYPP=UP(XPP)
      XP=XPP-YPP/DYPP
      DO 10 II=1,20
        YP=UU(XP)
        DYP=UP(XP)
        DD=XP-XPP
        AA=(2.*DYP+DYPP-3.*(YP-YPP)/DD)/DD
        BB=YP/DYP
        THE=XP-BB*(1.+BB*AA/DYP)
        ERR=ABS((THE-XP)/THE)
C       IF(II.GT.10.OR.IFRTY.EQ.1) PRINT*,'II,ERR,THE = ',II,ERR,THE
        IF(ERR.LT.1.E-6) GO TO 20
        XPP=XP
        XP=THE
        YPP=YP
        DYPP=DYP
 10   CONTINUE
 30   CONTINUE
      IFRTY=IFRTY+1
      GSS=GSS*2.
C     PRINT*,'II,ERR,THE = ',II,ERR,THE,GSS
      IF(IFRTY.LE.2) GO TO 40
      RETURN
 20   CONTINUE
      IF(THE.GT.DEL) GO TO 30
      RETURN
      END
      SUBROUTINE SETK0(NODE,NBAND,NEL,IFAXIS,MCON,SK,XX,YY,ANEL)
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     THIS SUBROUTINE SETS UP MATRIX K1(J1)
      DIMENSION XX(*),YY(*),SK(NBAND,*),ANEL(*)
      DIMENSION MCON(7,*)
      DIMENSION BAR(0:3),B(3),C(3),XE(3),YE(3)
C
C     CLEAR SK
      DO 10 I=1,NODE
        DO 10 J=1,NBAND
          SK(J,I)=0.
 10   CONTINUE
C
C  ASSEMBLE K INTO SK IN PACKED FORM.  RHS=Q*CHD INTO VV
C  LOOP OVER ALL ELEMENTS
      DO 200 IE=1,NEL
        BAR(3)=0.
        DO 210 I=1,3
          XE(I)=XX(MCON(I,IE))
          YE(I)=YY(MCON(I,IE))
          BAR(3)=BAR(3)+XE(I)*XE(I)+YE(I)*YE(I)
 210    CONTINUE
        B(1)=YE(2)-YE(3)
        B(2)=YE(3)-YE(1)
        B(3)=YE(1)-YE(2)
        C(1)=XE(3)-XE(2)
        C(2)=XE(1)-XE(3)
        C(3)=XE(2)-XE(1)
C
C  LOOP OVER NODES OF ELEMENT
        BAR(0)=1.
        BAR(1)=(XE(1)+XE(2)+XE(3))/3.
```

```
      BAR(2)=(YE(1)+YE(2)+YE(3))/3.
      BAR(3)=SQRT(BAR(3))
      A4=4.*ANEL(IE)/BAR(IFAXIS)
      DO 250 I=1,3
        IN=MCON(I,IE)
        DO 250 J=I,3
          JN=MCON(J,IE)
          LN=MIN(IN,JN)
          KN=IN-JN+1
          IF(JN.GT.IN) KN=JN-IN+1
          ELEK=(B(I)*B(J)+C(I)*C(J))/A4
          SK(KN,LN)=SK(KN,LN)+ELEK
 250    CONTINUE
 200  CONTINUE
      RETURN
      END
      SUBROUTINE SETQ2(NODE,NEL,DEBYE,Q,G,ANEL,MCON)
      IMPLICIT REAL*8 (A-H,O-Z)
C  THIS SUBROUTINE SETS UP THE RHS VECTOR Q
      DIMENSION Q(*),G(*),ANEL(*),MCON(7,*)
C
C  CLEAR Q
      DO 10 I=1,NODE
        Q(I)=0.
 10   CONTINUE
      DSQI=1.
      IF(DEBYE.GT.0.) DSQI=1./DEBYE/DEBYE
C
C  COMPUTE NODAL AREA AND CHARGE
      DO 20 IE=1,NEL
        A3=ANEL(IE)/3.*DSQI
        DO 20 I=1,3
          IN=MCON(I,IE)
          Q(IN)=Q(IN)+G(IE)*A3
 20   CONTINUE
      RETURN
      END
      SUBROUTINE ESSBC(SK,Q,FD,NRD,NODERD,NODE,NBAND)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SK(NBAND,*),Q(*),FD(*),NODERD(2,*)
      DO 10 I=1,NODE
        DO 10 IRD=1,NRD
          K=NODERD(1,IRD)
          IF(ABS(K-I).LT.NBAND) THEN
            IF(K.GT.I) Q(I)=Q(I)-SK(K-I+1,I)*FD(IRD)
            IF(K.LT.I) Q(I)=Q(I)-SK(I-K+1,K)*FD(IRD)
          ENDIF
 10   CONTINUE
      DO 20 IRD=1,NRD
        K=NODERD(1,IRD)
        SK(1,K)=1.
        Q(K)=FD(IRD)
        DO 30 J=2,NBAND
          SK(J,K)=0.
          IF(K-J.GE.0) SK(J,K-J+1)=0.
 30     CONTINUE
 20   CONTINUE
      RETURN
      END
      SUBROUTINE SOLV(A,B,NEQT,NBAND)
```

```
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(NBAND,*),B(*)
      NSOLVE=NEQT-1
      NB=NBAND-1
      JF=NEQT-NB
      DO 100 I=1,NSOLVE
        Q=1.0/A(1,I)
        IF(I.GT.JF) NB=NEQT-I
        NB1=NB+1
        DO 200 II=1,NB
          JI=I+II
          R=A(II-1,I)*Q
          IF(ABS(R).EQ.0.) GO TO 200
          B(JI)=B(JI)-R*B(I)
          JJ=NB1-II
          DO 300 IJ=1,JJ
            A(IJ,JI)=A(IJ,JI)-R*A(II+IJ,I)
300       CONTINUE
200     CONTINUE
100   CONTINUE
      NB=NBAND-1
      DO 400 I=1,NEQT
        Q=1./A(1,I)
        B(I)=B(I)*Q
        IF(I.EQ.NEQT) GO TO 400
        IB=MIN(NB,NEQT-I)
        DO 500 II=1,IB
          A(II+1,I)=A(II+1,I)*Q
500     CONTINUE
400   CONTINUE
      DO 600 I=1,NSOLVE
        J=NEQT-I
        IB=MIN(NB,I)
        DO 600 II=1,IB
          B(J)=B(J)-A(II+1,J)*B(II+J)
600   CONTINUE
      RETURN
      END
```

```
      PROGRAM HEMIV
      IMPLICIT REAL*8 (A-H,O-Z)
      CHARACTER TEST(101,101),ICHAR(10),LTMP(7)*14
      DIMENSION ITOT(101,101),NSUM(101),ISUM(101),JSUM(101),
     -PHOD(15),LSUM(101),MSUM(101),NECT(101),NAOT(101)
      DATA ICHAR/' ','2','3','4','5','6','7','8','9','9'/
      DATA ISUM,JSUM,LSUM,MSUM,NSUM,NECT,NAOT /707*0/
      DATA TEST /10201*' '/
      DO 10 I=1,41
        DO 10 J=1,41
          ITOT(I,J)=0
10    CONTINUE
      PI=ACOS(-1.)
      RAD=PI/180.
      THETA=90.
      THETA=THETA*RAD
      ST=SIN(THETA)
      M180=0
C
C  SET QUADRATURE LIMITS
      ME=41
      MP=41
      MR=11
      MA=11
      ISW6=1
      IF(ISW6.EQ.1) THEN
        PRINT*,'M180,ME,MP,MR,MA = ',M180,ME,MP,MR,MA,'  ENTER NEW VALUE
     -S'
        READ(5,*) M180,ME,MP,MR,MA
        PRINT*,'M180,ME,MP,MR,MA = ',M180,ME,MP,MR,MA
      ENDIF
C
C  DEFINITION OF PLATE AND APERTURE RADII
C
C  DEFINE GEOMETRY
      ENOT=1000.
      CALL GEOMA(VOUT,VINN,RIP,ROP,RIA,ROA,ENOT)
C
C  DEFINITION OF PLATE AND APERTURE RADII
      RB=(RIP+ROP)/2
      DRP=ROP-RIP
      DIA=ROA-RIA
      RA=DIA/2.
      EAL=DIA
      EKON=ROP*RIP/(ROP*ROP-RIP*RIP)
      VI=1./(EKON*(1.+RIP/ROP))
      VO=VI-1./EKON
      QQ=(VI-VO)/(1./RIP-1./ROP)
C
C  SET 180 DEG APERTURE PARAMETERS
      IF(M180.EQ.1) THEN
C  SLIT OF CONSTANT DELTA R
        RC=EAL/2.
        WRITE(6,'(10X,''APERTURE AT 180 IS SLIT.  WIDTH ='',F8.3,
     -  ''  CM'')') EAL
      ELSE IF(M180.EQ.2) THEN
C  CIRCLE OF RADIUS RC
        RC=RA
        WRITE(6,'(A1,6X,''APERTURE AT 180 IS CIRCLE.  RADIUS ='',F8.3,
     +''  CM'')') ' ',RC
```

```
          ELSE
C   DEFAULT IS NO APERTURE
            M180=0
            RC=(ROP-RIP)/2.
            WRITE(6,'(5X,''NO APERTURE AT 180 DEGREES'')')
          ENDIF
C
C   DEFINITION OF U QUADRATURE PARAMETERS
          UIP=RB/RIP
          UOP=RB/ROP
          UIA=RB/RIA
          UOA=RB/ROA
          UINC=(UIA-UOA)/MR
          UST=UOA+UINC/2
          IF(MR.LE.1) THEN
            MR=1
            UST=1.
          ENDIF
C
C   DEFINITIONS OF ALPHA QUADRATURE PARAMETERS
            ALFB1=-ASIN(RA/RB)
            ALFB2=-ALFB1
            ALFINC=(ALFB2-ALFB1)/MA
            ALFAST=ALFB1+ALFINC/2.
            IF(MA.LE.1) THEN
              MA=1
              ALFAST=0.
            ENDIF
C
C   DEFINITION OF EK QUADRATURE PARAMETERS
          EK1=0.85
          EK2=1.15
          EKINC=(EK2-EK1)/ME
          EFUD=.0099
          EFUD=0.
          EKST=EK1+EKINC/2.+EFUD
          DE=(VI-VO)/21.
          EB=1.-10.*DE
          IF(ME.LE.1) THEN
            ME=1
            EK1=1.
            EK2=1.
            EKINC=1.
            EKST=1.+EFUD
          ENDIF
C
C   DEFINITION OF PHI QUADRATURE PARAMETERS
          PHI1=-12.0/ST
          PHI2=12.0/ST
          PHI1=PHI1*RAD
          PHI2=PHI2*RAD
          PHINC=(PHI2-PHI1)/MP
          PHIST=PHI1+PHINC/2
          IF(MP.LE.1) THEN
            MP=1
            PHI1=0.
            PHI2=0.
            PHINC=1./ST
            PHIST=0.
          ENDIF
```

```
      ASUM=0
      RIA=RB-RC
      ROA=RB+RC
      UIA=RB/RIA
      UOA=RB/ROA
C
C  DO QUADRATURES
      MMR=(MR-1)/2+1
      MMA=(MA-1)/2+1
      MAT=1
      IF(M180.NE.2) THEN
        MAT=MA
        MMA=1
        MA=1
      ENDIF
      MB=MAX(MA,MAT)
      NTRJ=0
      DO 30 L=1,MR
        U=UST+(L-1)*UINC
        R=RB/U
        IF(MR.EQ.1) UINC=U*U/RB
        IF(MB.LE.1) ALFINC=U/RB
C
C  DEFINITIONS OF ALPHA QUADRATURE PARAMETERS
        DR=ABS(RB-R)
        CALF=(R*R+RB*RB-RA*RA)/2./RB/R
        ALFA1=-ACOS(MIN(1.,CALF))
        ALFA2=-ALFA1
        ALFA=0.
C
        DO 30 MM=1,MA
          IF(M180.EQ.2) THEN
            ALFA=ALFAST+(MM-1)*ALFINC
            IF(ALFA.LT.ALFA1.OR.ALFA.GT.ALFA2) GO TO 30
            SQ=SQRT(RC*RC-(RB*SIN(ALFA))**2)
            RCAL=RB*COS(ALFA)
            RIA=RCAL-SQ
            ROA=RCAL+SQ
            UIA=RB/RIA
            UOA=RB/ROA
          ENDIF
C
          DO 40 I=1,ME
            EK=EKST+(I-1)*EKINC
            EGY=EK+VI-QQ*(1./RIP-1./R)
            DO 40 J=1,MP
              PHI=PHIST+(J-1)*PHINC
C             CALL TRAJEC(RB,U,ALFA,THETA,PHI,EK,ITEST,RHO,UIP,UOP,UIA,U
C    +        OA)
              NTRJ=NTRJ+1
              CALL ELLPS(EGY,R,PHI/RAD,0.D0,270.D0,QQ,RIP,ROP,RIA,ROA,
     +        RR,BET,PMAX,RMAX,RMIN,R180,REND,ITEST,NTRJ)
              EEND=EK+VI-QQ*(1./RIP-1./RR)
              DO 60 M=1,MAT
                IF(M180.NE.2) THEN
                  ALFA=ALFAST+(M-1)*ALFINC
                ENDIF
                IF(MR.EQ.1.AND.MB.EQ.1) THEN
                  I1=I
                  I2=J
```

```
      ELSE IF(ME.NE.1) THEN
        I1=I
        IF(MP.NE.1) THEN
          I2=J
        ELSE IF(MR.NE.1) THEN
          I2=L
        ELSE
          I2=MAX(M,MM)
        ENDIF
      ELSE IF(MP.NE.1) THEN
        I2=J
        IF(MR.NE.1) THEN
          I1=L
        ELSE
          I1=MAX(M,MM)
        ENDIF
      ELSE
        I1=L
        I2=MAX(M,MM)
        MMR=MR
      ENDIF
      TEST(I1,I2)='Q'
      IF(M180.NE.2.AND.(ALFA.LT.ALFA1.OR.ALFA.GT.ALFA2)) GO TO
     + 60
      TEST(I1,I2)=ICHAR(ITEST)
      IF(ITEST.NE.1) GO TO 60
      ISUM(I)=ISUM(I)+1
      JSUM(J)=JSUM(J)+1
      LSUM(L)=LSUM(L)+1
      MSUM(M)=MSUM(M)+1
      ASUM=ASUM+1./U/U/U
      ITOT(I,J)=ITOT(I,J)+1
      NRHO=(REND-RIP)/(ROP-RIP)*21.+1.
      NRHO=MIN(MAX(1,NRHO),21)
      NSUM(NRHO)=NSUM(NRHO)+1
      NEO=(EEND-VO-1.)/(VI-VO)*21.+1.
      NEO=MIN(MAX(1,NEO),21)
      NAO=(BET+8.)/16.*21.+1.
      NAO=MIN(MAX(1,NAO),21)
      NEOT(NEO)=NEOT(NEO)+1
      NAOT(NAO)=NAOT(NAO)+1
60          CONTINUE
40        CONTINUE
          IF(L.EQ.MMR.AND.MM.EQ.MMA) THEN
            IF(I1.GT.1.AND.I2.GT.1) THEN
              DO 120 JJ=1,MIN(41,I2)
                WRITE(6,'(1X,41A3)') (TEST(I,JJ),I=1,MIN(41,I1))
120           CONTINUE
            ENDIF
          ENDIF
30      CONTINUE
        IF(I1.GT.1.AND.I2.GT.1) THEN
          WRITE(6,33) PHI1/RAD
33        FORMAT(//' PHI START=',F5.1,1X,'DEGREES')
          DO 80 II=1,MIN(41,MP)
            WRITE(6,'(1X,41I3)') (ITOT(I,II),I=1,MIN(41,ME))
80        CONTINUE
          WRITE(6,34) PHI2/RAD
34        FORMAT(1X,'PHI END=',F4.1,1X,'DEGREES')
          WRITE(6,35) EK1,EK2
```

```
35      FORMAT(1X,'ENERGY START=',F7.5,85X,'ENERGY END=',F7.5)
        ENDIF
        WRITE(6,100)
100     FORMAT(//8X,'EBEG',12X,'PHI',14X,'R',12X,'ALP',11X,'EEND',11X,
     -  BEND',12X,'RHO')
        DO 24 I=1,MAX(MR,MB,ME,MP,21)
          LTMP(1)=' '
          LTMP(2)=' '
          LTMP(3)=' '
          LTMP(4)=' '
          LTMP(5)=' '
          LTMP(6)=' '
          LTMP(7)=' '
          EK=EKST+(I-1)*EKINC
          PHI=PHIST+(I-1)*PHINC
          DPHI=PHI/RAD
          U=UST+(I-1)*UINC
          R=1./U
          ALFA=ALFAST+(I-1)*ALFINC
          EO=EB+FLOAT(I-1)*DE
          BO=-8.+(FLOAT(I)-.5)*16./21.
          RO=RIP+(FLOAT(I)-.5)*(ROP-RIP)/21.
          ISS=ISUM(I)+JSUM(I)+LSUM(I)+MSUM(I)+NECT(I)+NAOT(I)+NSUM(I)
          IF(ISS.LE.0) GO TO 24
          IF(I.LE.ME) WRITE(LTMP(1),4001) ISUM(I),EK
          IF(I.LE.MP) WRITE(LTMP(2),4001) JSUM(I),DPHI
          IF(I.LE.MR) WRITE(LTMP(3),4001) LSUM(I),R
          IF(I.LE.MB) WRITE(LTMP(4),4001) MSUM(I),ALFA/RAD
          IF(I.LE.21) WRITE(LTMP(5),4001) NEOT(I),EO
          IF(I.LE.21) WRITE(LTMP(6),4001) NAOT(I),BO
          IF(I.LE.21) WRITE(LTMP(7),4001) NSUM(I),RO
4001      FORMAT(I4,F10.5)
          WRITE(6,6) LTMP
 24     CONTINUE
 6      FORMAT(7(1X,A14))
C       WRITE(6,101)
        IISM=0
        DO 23 I=1,I1
          IISM=IISM+ISUM(I)
 23     CONTINUE
        GF=(ASUM)*RB*RB*ST*ST*PHINC*UINC*EKINC*ALFINC
        THETA=THETA/RAD
        WRITE(6,102)
 102    FORMAT(1X/1X/1X,'***THETA**SUM OVER ALL GEOMETRIC FACTOR')
        WRITE(6,9)THETA,IISM,GF
 9      FORMAT(1X,F10.5,I10,1PE15.5)
        IF(ME.GT.2) THEN
          CALL FWHM(ME,ISUM,EKST,EKINC,EBAR,SIGE,ERAN,MAXX)
          ERAN2=FLOAT(IISM)*EKINC/FLOAT(MAXX)
 2001     FORMAT(//1X,'EBAR,SIGE,  DELTA E OVER E  = ',4F10.5)
          WRITE(6,2001) EBAR,SIGE,ERAN/MAX(EBAR,1.D-6),ERAN2
        ENDIF
        IF(MP.GT.2) THEN
          CALL FWHM(MP,JSUM,PHIST,PHINC,PBAR,SIGP,PRAN,MAXX)
          PRAN2=FLOAT(IISM)*PHINC/FLOAT(MAXX)/RAD
          WRITE(6,2002) PBAR/RAD,SIGP/RAD,PRAN/RAD,PRAN2
 2002     FORMAT(//1X,'PBAR,SIGP,PFWHM                = ',4F10.5)
        ENDIF
        IF(MR.GT.2) THEN
          CALL FWHM(MR,LSUM,UST,UINC,UBAR,SIGR,URAN,MAXX)
```

```
      URAN2=FLOAT(IISM)*UINC/FLOAT(MAXX)
      WRITE(6,2003) 1./UBAR,SIGR,URAN,URAN2
2003  FORMAT(//1X,'RBAR,SIGR,RFWHM                  = ',4F10.5)
     ENDIF
     IF(MB.GT.2) THEN
      CALL FWHM(MB,MSUM,ALFAST,ALFINC,ABAR,SIGA,ARAN,MAXX)
      ARAN2=FLOAT(IISM)*ALFINC/FLOAT(MAXX)/RAD
      WRITE(6,2004) ABAR/RAD,SIGA/RAD,ARAN/RAD,ARAN2
2004  FORMAT(//1X,'ABAR,SIGA,AFWHM                  = ',4F10.5)
     ENDIF
     DE=.12/21.
     EB=.94-DE/2.
     CALL FWHM(21,NECT,EB,DE,EOBR,SIGE,EORAN,MAXX)
     WRITE(6,2005) EOBR,SIGE,EORAN
2005 FORMAT(//1X,'EOBR,SIGE,EFWHM                  = ',3F10.5)
     DB=16./21.
     BB=-8.-DB/2.
     CALL FWHM(21,NACT,BB,DB,BOBR,SIGB,BORAN,MAXX)
     WRITE(6,2006) BOBR,SIGB,BORAN
2006 FORMAT(//1X,'BOBR,SIGB,BFWHM                  = ',3F10.5)
     DR=(ROP-RIP)/21.
     RHOB=RIP+DR/2.
     CALL FWHM(21,NSUM,RHOB,DR,ROBR,SIGR,RORAN,MAXX)
     WRITE(6,2007) ROBR,SIGR,RORAN
2007 FORMAT(//1X,'ROBR,SIGR,RFWHM                  = ',3F10.5)
     END
     SUBROUTINE TRAJEC(RB,U,ALFA,THETA,PHI,EK,ITEST,RHO,UIP,UOP,UIA,UOA
    +)
     IMPLICIT REAL*8 (A-H,O-Z)
     SAVE
     DATA NCALL/0/
     IF(NCALL.NE.0) GO TO 10
     PI=ACOS(-1.)
     TPI=2.*PI
     RAD=PI/180.
     RAD270=270.*RAD
     CB=COS(0.*RAD)
     RHO=0.
     SB=SIN(0.*RAD)
10   CONTINUE
     NCALL=NCALL+1
     W=EK+2*(U/UIP/UOP-1)
C  CALCULATE TRIG QUANTITIES
     SA=SIN(ALFA)
     CA=COS(ALFA)
     CT=COS(THETA)
     ST=SIN(THETA)
     SF=SIN(PHI)
     CF=COS(PHI)
C  MAKE ANGULAR TRANSFORMATION TO THE TRAJECTORY PLANE
     X1=-SA*ST*SF+CA*CT
     Y1=ST*CF
     G=SQRT(X1*X1+Y1*Y1)
     SG=X1/G
     CG=Y1/G
     X2=CA*ST*SF+SA*CT
     Y2=-SG*CA*CT+SG*SA*ST*SF-ST*CF*CG
     C2W=Y2*Y2/(X2*X2+Y2*Y2)
C  CALCULATE ORBIT CONSTANT
     UP=U*U/W/C2W
```

```
      ESX=U*X2/Y2
      ECX=U-UP
      CHIP=ATAN2(ESX,ECX)
      UPEPS=SQRT(ESX*ESX-ECX*ECX)
      UE=UP-UP-U
      XA=(UOP-UP)/UPEPS
      IF(ABS(XA).LE.1.) THEN
        XA=ACOS(XA)
        CHIA=XA-CHIP
        CHIB=-XA+CHIP
        IF(CHIA.LT.0.) CHIA=CHIA+TPI
        IF(CHIB.LT.0.) CHIB=CHIB+TPI
        IF(CHIA.GT.TPI) CHIA=CHIA-TPI
        IF(CHIB.GT.TPI) CHIB=CHIB-TPI
        IF(CHIB.GE.PI.AND.CHIB.LT.RAD270) CHIA=CHIB
      ELSE
        CHIA=0.
      ENDIF
      XB=(UIP-UP)/UPEPS
      IF(ABS(XB).LE.1.) THEN
        XB=ACOS(XB)
        CHIC=XB+CHIP
        CHID=-XB+CHIP
        IF(CHIC.LT.0.) CHIC=CHIC+TPI
        IF(CHID.LT.0.) CHID=CHID+TPI
        IF(CHIC.GT.TPI) CHIC=CHIC-TPI
        IF(CHID.GT.TPI) CHID=CHID-TPI
        IF(CHID.GE.PI.AND.CHID.LT.RAD270) CHIC=CHID
      ELSE
        CHIC=0.
      ENDIF
C
C  DOES THE ORBIT GO THROUGH THE ANALYZER?
C  IS THE FIRST EXTREMUM A MAXIMUM OR A MINIMUM?
      IF(CHIP.GT.0..AND.UIP.LE.UP+UPEPS) THEN
C  A MAXIMUM - DOES IT HIT THE INNER PLATE?
        ITEST=3
C  A MINIMUM - DOES IT HIT THE OUTER PLATE?
      ELSE IF(CHIP.LE.0..AND.UP-UPEPS.LE.UOP)THEN
        ITEST=2
      ELSE IF(UE.GT.UIP) THEN
        ITEST=3
      ELSE IF(UE.LE.UOP) THEN
        ITEST=2
C  DOES IT GO THROUGH THE EXIT APERTURE OF THE HEMISPHERE?
      ELSE IF(UE.GT.UIA) THEN
        ITEST=5
      ELSE IF(UE.LE.UOA) THEN
        ITEST=4
C  WOULD IT HIT THE OUTER PLATE IF IT WENT FAR ENOUGH?
      ELSE IF(CHIP.GT.0..AND.UP-UPEPS.LE.UOP.AND.CHIA.GE.PI.AND.CHIA.LT.
     +RAD270) THEN
C  DOES THIS HAPPEN INSIDE THE QUADRISPHERE?
        ITEST=6
C  WOULD IT HIT THE INNER PLATE IF IT WENT FAR ENOUGH?
      ELSE IF(CHIP.LE.0..AND.UIP.LE.UP+UPEPS.AND.CHIC.GE.PI.AND.CHIC.LT.
     +RAD270) THEN
C  DOES THIS HAPPEN INSIDE THE QUADRISPHERE?
        ITEST=7
      ELSE
```

```
      ITEST=1
      XR=CA*CG
      YR=CB*SG-SA*SB*CG
      RHO=ATAN2(XR,YR)
    ENDIF
C     WRITE(6,3001) NCALL,RB/U,PHI/RAD,RB/UIP,RB/(UP+UPEPS),RB/UP,RB/
C    - UP-UPEPS),RB/UOP,RB/UE,CHIP/RAD,CHIA/RAD,CHIC/RAD,ITEST
 3001 FORMAT(1X,I4,F8.3,F8.2,6F8.3,3X,3F8.2,I4)
      RETURN
      END
      SUBROUTINE FWHM(NE,IESM,EKST,EKINC,EBAR,SIG,ERAN,MAXX)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION IESM(*)
      SAVE
      MAXX=IESM(1)
C
C  DETERMINE EBAR, SIGMA
      NN=0
      EBAR=0.
      SIG=0.
      YSUM=0
      SQSM=0.
      DO 10 II=1,NE
        NN=NN+IESM(II)
        YY=EKST+(II-1)*EKINC
        YSUM=YSUM+YY*IESM(II)
        SQSM=SQSM+YY*YY*IESM(II)
 10   CONTINUE
      IF(NN.GE.3) THEN
        EBAR=YSUM/NN
        SIG=(SQSM-EBAR*EBAR*NN)/(NN-1)
        IF(SIG.GT.0.) SIG=SQRT(SIG)
      ENDIF
      MAXCH=1
      MAXX=IESM(1)
      DO 50 I=2,NE
        IF(IESM(I).GT.MAXX) THEN
          MAXX=IESM(I)
          MAXCH=I
        ENDIF
 50   CONTINUE
      HMAX=FLOAT(MAXX)/2.
      CH1=0.
      CH2=NE
      DEN=1.
      DO 60 I=1,MAXCH
        IF(HMAX.GT.FLOAT(IESM(I)).AND.HMAX.LE.FLOAT(IESM(I+1))) THEN
          DEN=IESM(I+1)-IESM(I)
          IF(ABS(DEN).LT.1.E-6) DEN=1.
          CH1=I-1+(HMAX-FLOAT(IESM(I)))/DEN
        ENDIF
 60   CONTINUE
      DO 70 I=NE,MAX(MAXCH,2),-1
        IF(HMAX.GT.FLOAT(IESM(I)).AND.HMAX.LE.FLOAT(IESM(I-1))) THEN
          DEN=IESM(I-1)-IESM(I)
          CH2=I-1-(HMAX-FLOAT(IESM(I)))/DEN
        ENDIF
 70   CONTINUE
      CCH1=EKST+CH1*EKINC
      CCH2=EKST+CH2*EKINC
```

```
      ERAN=(CH2-CH1)*EKINC
      RETURN
      END
      SUBROUTINE ELLPS(EKE,RP,BET,THE,DEL,QQ,RIP,ROP,RIA,ROA,RR,BETA,
     -PMAX,RMAX,RMIN,R180,R270,ITEST,NTRJ)
      IMPLICIT REAL*8 (A-H,O-Z)
      LOGICAL QMX,QMN,QTP,QBT,QTC,QBC,QEX
      SAVE
      DATA NCALL /0/
      IF(NCALL.EQ.0) THEN
        PI=ACOS(-1.)
        PI32=1.5*PI
        RTOD=180./PI
        NCALL=1
      ENDIF
      RDEL=DEL/RTOD
      RBET=BET/RTOD
      RTHE=THE/RTOD
      EKC=QQ/(2.*RP)
      CC=EKC/EKE/COS(RBET)**2
      UURT=CC-TAN(RBET)*SIN(RDEL)+(1.-CC)*COS(RDEL)
      RR=RP/UURT
      PMAX=PI/2.
      IF(CC.NE.1.) PMAX=-ATAN(TAN(RBET)/(1.-CC))
      UUPM=CC-TAN(RBET)*SIN(PMAX)+(1.-CC)*COS(PMAX)
      UUQM=CC+TAN(RBET)*SIN(PMAX)-(1.-CC)*COS(PMAX)
      U180=CC-TAN(RBET)*SIN(PI-RTHE)+(1.-CC)*COS(PI-RTHE)
      U270=CC-TAN(RBET)*SIN(PI32-RTHE)+(1.-CC)*COS(PI32-RTHE)
      RMAX=RP/UUPM
      RMIN=RP/UUQM
      R180=RP/U180
      R270=RP/U270
      PMAX=PMAX*RTOD+THE
      IF(PMAX.LT.0.) PMAX=PMAX+360.
      IF(PMAX.GT.360.) PMAX=PMAX-360.
      BETN=(1.-CC)*SIN(RDEL)+TAN(RBET)*COS(RDEL)
      BETD=CC+(1.-CC)*COS(RDEL)-TAN(RBET)*SIN(RDEL)
      BETA=0.
      IF(BETD.NE.0.) BETA=ATAN(BETN/BETD)*RTOD
      IF(BETA.GT.90.) BETA=BETA-360.
      IF(BETA.LT.-90.) BETA=BETA+360.
C
C  ITEST LOGIC
      IF(RMAX.GT.RMIN) THEN
        PMIN=PMAX+180.
      ELSE
        RT=RMAX
        RMAX=RMIN
        PT=PMAX
        PMAX=PMAX+180.
        RMIN=RT
        PMIN=PT
      ENDIF
      IF(PMAX.LT.0.) PMAX=PMAX+360.
      IF(PMIN.LT.0.) PMIN=PMIN+360.
      IF(PMAX.GT.360.) PMAX=PMAX-360.
      IF(PMIN.GT.360.) PMIN=PMIN-360.
      QMX=PMAX.GT.THE.AND.PMAX.LE.THE+DEL.AND.RMAX.GE.ROP
      QMN=PMIN.GT.THE.AND.PMIN.LE.THE+DEL.AND.RMIN.LE.RIP
      IF(QMX.AND.QMN) THEN
```

```
      READ(4,*,END=100) NRP,(IN(I),RA(I),I=1,NRP)
      CALL VEXP(NRP,IN,RA)
C
      RIP=RA(IAP(3,2))
      ROP=RA(IAP(4,2))
      RIA=RA(IAP(3,1))
      RCA=RA(IAP(4,1))
      WRITE(6,'(11X,''DIAMETER OF ENTRANCE APERTURE = '',F7.3,'' CM'')')
     -RCA-RIA
      WRITE(6,'(5X,''INNER AND OUTER RADIUS OF INSTRUMENT = '',2F7.3,
     -'' CM'')') RIP,ROP
      WRITE(6,'(8X,''INNER AND OUTER RADIUS AT 180 DEG = '',2F7.3
     -)') RA(IAP(3,3)),RA(IAP(4,3))
      WRITE(6,'(7X,''INNER AND OUTER RADIUS AT EXIT APP = '',2F7.3
     -)') RA(IAP(3,4)),RA(IAP(4,4))
C
      RKON=(1./RIP-1./ROP)
      EKON=ENCT*(ROP+RIP)*RKON
      VINN=EKON/(1.+RIP/ROP)
      VOUT=VINN-EKON
      RETURN
  100 CONTINUE
      STOP 'NXTIN'
      END
      SUBROUTINE VEXP(NRP,IN,RR)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION IN(*),RR(*)
      DO 10 II=NRP,2,-1
        RR(IN(II))=RR(II)
        DR=(RR(II)-RR(II-1))/FLOAT(IN(II)-IN(II-1))
        DO 20 JJ=IN(II)-1,IN(II-1)+1,-1
          RR(JJ)=RR(JJ+1)-DR
   20   CONTINUE
   10 CONTINUE
      RETURN
      END
```

```
          QMX=QMX.AND.PMAX.LT.PMIN
          QMN=.NOT.QMX
        ENDIF
        QTP=QMX.OR.RP.GT.ROP.OR.RR.GE.ROP
        QBT=QMN.OR.RP.LT.RIP.OR.RR.LE.RIP
        QTC=THE.LT.180..AND.THE+DEL.GE.180..AND.R180.GE.ROA.AND.R180.LT.
     -ROP
        QBC=THE.LT.180..AND.THE+DEL.GE.180..AND.R180.LE.RIA.AND.R180.GT.
     -RIP
        QEX=THE.LT.270..AND.THE+DEL.GE.270.AND.R270.LT.ROP.AND.R270.GT.RIP
C
        IF(QTP.OR.QTC) THEN
C  HITS TOP PLATE WITHIN THE + DEL INTERVAL
          IF(QTP.AND.(PMAX.LE.180..OR.R180.GT.ROA)) THEN
            ITEST=2
          ELSE IF(QTC) THEN
            ITEST=4
          ELSE
            ITEST=6
          ENDIF
        ELSE
          ITEST=1
        ENDIF
        IF(QBT.OR.QBC) THEN
C  HITS BOTTOM PLATE WITHIN INTERVAL
          IF(QBT.AND.(PMIN.LE.180..OR.R180.LT.RIA)) THEN
            JTEST=3
          ELSE IF(QBC) THEN
            JTEST=5
          ELSE
            JTEST=7
          ENDIF
        ELSE
          JTEST=1
        ENDIF
        IF(ITEST.NE.1.AND.JTEST.NE.1) ITEST=MIN(ITEST JTEST)
        IF(ITEST.EQ.1) ITEST=JTEST
        RETURN
        END
        SUBROUTINE GEOMA(VOUT,VINN,RIP,ROP,RIA,ROA,ENOT)
        IMPLICIT REAL*8 (A-H,O-Z)
        DIMENSION IN(65),XA(65),XT(65),RA(65),
     +YT(65),IAP(4,4),PA(65)
        CHARACTER*80 IHED
C
        RTOD=180./ACOS(-1.)
C
C  READ INSTRUMENT HEADER CARD
        OPEN(4,FILE='TAPE4.INS')
        READ(4,'(A80)',END=100) IHED
        WRITE(6,'(1H1//5X,A)') IHED
C
C  READ LOGIC CARD
        READ(4,2001,END=100) NX,NY,NL,NV,NIA,NOA,NCA,IPRT
 2001   FORMAT(4I5,2X,3I1,I5)
C
C  READ INPUT APERTURE CARD
        READ(4,*,END=100) IAP
C
C  READ R CARD INPUT AND EXPAND
```